DOCUMENT RESUME

ED 329 433	SE 051 955

AUTHOR	Scanlon, Andrew, Ed.; And Others
TITLE	Behind the Scenery.
INSTITUTION	Tasmanian Education Dept., Hobart (Australia).
REPORT NO	ISBN-0-7246-14133
PUB DATE	90
NOTE	175p.; Photographs may not reproduce well.
AVAILABLE FROM	The Marketing Officer (Curriculum Services), Department of Education and The Arts, 71 Letitia Street, North Hobart, Tasmania, Australia 7000 ($A19.95 plus postage/pay on invoice).
PUB TYPE	Guides - Classroom Use - Teaching Guides (For Teacher) (052)
EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	Earth Science; *Environmental Influences; Foreign Countries; *Geology; Groundwater; Mining; Oceanography; Physical Environment; *Physical Geography; Plate Tectonics; *Resource Materials; Secondary Education; *Secondary School Science; Soil Science; Wind (Meteorology)
IDENTIFIERS	*Australia (Tasmania)

ABSTRACT

Knowledge of the physiographic evolution of the Tasmanian landscape is still very far from complete; however, all aspects of the landscape are governed by definable processes acting on the rock medley which is the heritage of Tasmania's geological history. This book explains Tasmania's landforms and geology in terms of geologic processes. Chapters include: (1) "Our Changing Earth"; (2) "Weathering"; (3) "Soils and Soil Erosion"; (4) "Groundwater"; (5) "The Development of Rivers"; (6) "Waves and Coastlines"; (7) "Glaciation and Tasmania"; (8) "The Effects of Wind"; and (9) "The Geological History of Tasmania". A summary of the geological history of Tasmania is appended. (KR)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED329433

SE 051 955

"PERMISSION TO REPRODUCE THIS
MATERIAL HAS BEEN GRANTED BY
H. Hocking

TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)."

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)
☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

BEHIND THE SCENERY

Tasmania's landforms and geology

BEST COPY AVAILABLE

BEHIND
THE
SCENERY

BEHIND
THE
SCENERY

Edited by

Andrew P. Scanlon • Graham J. Fish • Murray L. Yaxley

DEPARTMENT OF EDUCATION AND THE ARTS
TASMANIA AUSTRALIA

© Department of Education and The Arts Tasmania Australia

This work is copyright. No part may be reproduced without written permission from the Secretary, Department of Education and The Arts, Tasmania, Australia.

Marketing and sales inquiries should be directed to the Superintendent,
Curriculum Resources, Department of Education and The Arts,
71 Letitia St., Hobart, Tasmania 7000, Australia.

Publication Officer: Vernon Nase
Concept design, layout and artwork: Les Cousins
Typesetting: Louise Green and Sandra Pyke
Cover photograph courtesy of Department of Parks, Wildlife and Heritage

ASCIS Cataloguing in Publication entry
(prepared by TASCIS)

Behind the scenery / edited by Andrew P. Scanlon, Graham J. Fish, Murray L. Yaxley.

Bibliography.
Includes index.
ISBN 0 7246 1413 3

1. Geology – Tasmania
I. Scanlon, Andrew P. II. Fish, Graham J. III. Yaxley, Murray L.
IV. Tasmania. Department of Education and The Arts
559.46 DDC 20
559.46 ADDC 11

Printed and published by the Department of Education and The Arts
Tasmania Australia 1990
88/0117

Foreword

A book like this has been needed for a long time.

Knowledge of the physiographic evolution of the Tasmanian landscape is still very far from complete. Substantial discoveries, and no doubt some surprises, await any who care to make systematic observations and to interpret carefully what they see, and this may be done profitably almost anywhere in Tasmania.

Important work has been done in recent years by Dr. J. L. Davies, but he needs many more students and collaborators to extend the work. Visitors from the Australian National University have also contributed significantly, but so much more remains to be done. Enlightened amateurs like Robert Johnston and Arndell Lewis made brilliant pioneering studies. Professional geologists throughout the years have made scattered observations, almost always merely incidentally to other projects, but good physiographic work needs to be done in its own right.

All aspects of the landscape— rivers, beaches, harbours, shorelines, escarpments and so on are living, in the sense that they have a past, a present and a future, which are governed by definable processes acting on the rock medley which is the heritage of Tasmania's geological history. These processes in general and their application to each particular case must be thoroughly understood if civil engineers are to plan safely their good works for the greater comfort and safety of mankind, for natural processes can be co-operative when steered and guided, but ruthlessly destructive and derisive when naively thwarted. Men who mine detrital minerals such as gold, osmiridium, rutile, monazite, ilmenite, or diamonds and rubies, must also know thoroughly the past and present of the processes which have concentrated them here but not there. And there are other such coldly economic matters arising from this book.

Yaxley and Fish are both able and enthusiastic teachers (a headmaster is still a teacher), who of course want our scholars to pass examinations (for which reason this book has been prescribed for matriculation students). But the first goal of the authors is that all of us should look at our superb Tasmanian scenery with wisdom and appreciation in our gaze.

S. WARREN CAREY,
Professor of Geology,
University of Tasmania.

---

* This is the original foreword to *Behind the Scenery: the geological background to Tasmanian landforms* (1966). The original *Behind the Scenery* was written by Graham Fish and Murray Yaxley. The enduring popularity of this first *Behind the Scenery* has led to its substantial revision and the addition of much new material in *Behind the Scenery* (1990).

Contents

Foreword ... v
Preface ... ix

Chapter 1: Our changing earth

The Earth's origin and internal structure ... 1
The Earth's rocks and minerals ... 1
Change and geological time ... 3
Measuring geological time ... 4
The Earth's changing climate ... 6
Surface changes caused by processes within the Earth ... 9
Summary ... 11

Chapter 2: Weathering

Introduction ... 13
Processes of weathering ... 14
Chemical weathering: decomposition ... 15
The decomposition of rocks ... 16
Physical weathering - disintegration ... 18

Chapter 3: Soils and soil erosion

The link between soil types and scenery ... 23
Soil: some definitions ... 23
How are soils developed? ... 24
What determines soil type? ... 25
Succession ... 25
Soil profiles ... 26
Soil types in Tasmania ... 28
The fertility of Tasmanian soils ... 31
Soil erosion ... 31
Soil conservation ... 35

Chapter 4: Groundwater

Introduction ... 37
Groundwater and the rock cycle ... 41
The groundwater resource in Tasmania ... 44
Karst ... 48

Chapter 5: The development of rivers

Introduction ... 53
The work of rivers ... 57
Drainage patterns ... 60
Longitudinal profiles ... 63
River capture ... 67
River systems in Tasmania ... 70

Chapter 6: Waves and coastlines

Introduction 81
Wave refraction and shoreline features 83
Marine deposition 91
History of the Tasmanian coastline 95

Chapter 7: Glaciation and Tasmania

Introduction 99
The formation of glaciers and ice sheets 100
Landforms of glacial erosion 104
Glacial deposits and associated landforms 107
Quaternary multiple glaciation 110
Alpine periglacial environments 114

Chapter 8: The effects of wind

Introduction 117
The wind's load 118
Erosion by the wind 118
Sand dunes 119
The effects of wind on Tasmanian landforms 121

Chapter 9: The geological history of Tasmania

The first rocks 125
Fire and water 127
Quiet times 132
Folds, melts and tin 133
Icebergs and swamps 135
The great invasion 139
Tasmania takes shape 140
Moving north 141
Changing climate 143

Appendix 148
Bibliography 152
Index 159

Preface

Since *Behind the Scenery* was first published in 1966 much progress has been made on the understanding of Tasmanian landforms. Important contributions have been made by Dr. Eric Colhoun (now Professor of Geography at the University of Newcastle), Albert Goede, Neil Chick and their students at the University of Tasmania's Department of Geography and Environmental Studies. Geologists from the Hydro Electric Commission, the Department of Mines and the University of Tasmania's Geology Department (particularly Dr. Max Banks) have also made important contributions.

The initial plans to revise the original 1966 edition of *Behind the Scenery* involved work by Higher School Certificate Geology teachers. The task was a major one and required a large-scale re-writing and re-emphasis of material in the original publication. Several of the chapters in this book are entirely new. The others contain major revisions of the information in the 1966 publication. The names of the authors or principal revisers are listed at the head of each chapter. As well as these individuals we would like to acknowledge the contributions of the following:

- Tim Doe, Roger Edwards, Roy Pallett, Bob Millington, Bob Richardson and Bruce Palmer for their work on the initial revision of different parts of the text.
- Neil Chick for his assistance with 'Waves and Coastlines'.
- Albert Goede for his assistance with 'Groundwater' and 'The Development of Rivers'.
- Bill Cromer, Lloyd Matthews, Bert Moore and Peter Stevenson for providing much of the information for the section 'The Groundwater Resource in Tasmania' in 'Groundwater'.
- Paul Augustinus, Dr. Kevin Kiernan, Sep Paterson and David Wilson for their contributions to different parts of the book— particularly 'The Development of Rivers'.
- Dr. Max Banks, Dr. Clive Burrett, Dr. Geoff Green, Peter Baillie and Dr. Emyr Williams for their assistance with earlier drafts of the 'Geological History of Tasmania'.

The assistance of all these people has been invaluable in preparation of this document. Any factual errors or omissions are, however, the responsibility of the editors and the authors.

We would finally like to acknowledge the major contribution of Vernon Nase and Les Cousins of the Education Department's Curriculum Resources Section for their creative and patient work in the sub-editing, design and artwork of this book. We also wish to thank David Enright and other staff of the Curriculum Resources Section for their contributions.

We hope this book proves of value to students and people generally interested in Tasmania's rich geological and geomorphological heritage.

Andrew Scanlon
Graham Fish
Murray Yaxley

Acknowledgements

The editors wish to thank all the owners of copyright who have granted permission for the reproduction of copyright material in this publication. In this context we acknowledge the generous contribution made by the following publishers and individuals:

Adrian Bowden
American Association of Petroleum Geologists
Department of Parks, Wildlife and Heritage (Tasmania) for the aerial photographs used in this publication
Elsevier Scientific Publications
Unwin Hyman Ltd.
John Wiley and Sons, Inc.
Professor J.J. Veevers
Professor M.A.J. Williams
Oxford University Press
The Wilderness Society, Inc. (Tasmania)

Figure acknowledgements

1.1, 1.2, 1.3, 1.4, 1.7, 1.8, 1.15, 1.16, 1.17, 1.18, 9.1, 9.2, 9.4, 9.7, 9.11, 9.13, 9.16, 9.19, 9.23, 9.25, 9.28, 9.29, 9.31, 9.36, 9.39, 9.41, 9.47, 9.48, 9.51, 9.55, 9.57 from Scanlon, A., (1984), *The Geology of Tasmania*, Education Department, Hobart, Tasmania.
1.5 from Carey, 1962.
1.9 from U.S. Committee for Garp, 1975.
1.10 from Frakes, 1979.
1.11 after Bradley, 1984.
1.12, 1.13 from Veevers (ed.), 1984.
1.19 after Veevers (ed.), 1984.
2.1, 6.25 Denis Bell.
2.2 G.Dowl.
2.5 from Strakhov, 1967.
2.8, 2.9, 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, 4.6, 4.7, 4.17, 4.18, 5.6, 5.13, 6.13, 6.14, 6.15, 6.17, 8.7, 8.8, 9.3, 9.6, 9.9, 9.10, 9.20, 9.21, 9.22, 9.24, 9.30, 9.37, 9.44, 9.45, 9.46, 9.49, 9.50, 9.52, 9.53, 9.58, 9.60 from Banks, M.R. (1978), *Foundations of Our Scenery*, Education Department, Hobart, Tasmania.
3.5 after Nicholls and Dimmock, 1965.
3.6, 3.7, 3.8, 3.9 from Tivendale, B. (1983) *Soil Conservation*, Education Department, Hobart, Tasmania.
4.3 after Press and Siever, 1974.
4.11 after Flint and Skinner, 1974.
4.12 from Tasmanian Year Book.
4.13 from Cromer, 1979 and 4.14 after Cromer, 1979.
4.15 from Goede, 1971.
4.16 from Jennings, 1971.
4.19, 4.20 from Bunton and Eberhard, 1984.
4.21, 5.35, 9.59 F.Koolhof.
5.4, 5.9 from Chorley et al , 1984.
5.5, 5.11, 5.40, 5.41, 6.20, 6.40 Department of Parks, Wildlife and Heritage (Tas.).
5.8 after Olive, 1974.
5.14 from Howard, 1967.
5.16 after Ford, 1956.
5.21, 5.31, 5.32, 5.33, 5.34 from the Wilderness Society (Tasmania).
5.22 Don Stephens.
5.25 Frank Hurley.
5.28 from Colhoun, 1980.
5.29 after Banks, 1962.
5.37 from Carey, 1947.
5.39 after Alwar, 1960.
6.6 E. Hiller.
6.7 after Davies, 1960.
6.10 Don Stephens.
6.22 after Jennings, 1959a.
6.23 from Banks, M.R., et al., 1977.
6.24 after Admiralty Chart 960.
7.1 after Davies, 1967.
7.2 after Paterson, 1981.
7.4 after Sugden and John, 1976.
7.12 after Flint, 1971.
7.18 from Colhoun, 1985.
7.21 from Hannan and Colhoun, 1987.
7.23 data provided by Neil Gibson.
7.24 P. Sansom.
8.5 from Flint and Skinner, 1974.
8.10 from Bowden, 1983.
9.5 Chris St.John, Savage River Mines.
9.12 by K. Williams, supplied by R. Reeves, Antarctic Division, Kingston.
9.15 after Corbett and Lees, 1987.
9.17 by R. Larson, Lamont-Doherty Geological Observatory, New York. Supplied by M. Solomon, Bureau of Mineral Resources.
9.18 after McKerrow, 1978.
9.26 after discussions with M.R. Banks, University of Tasmania.
9.27 K. Kiernan, University of Tasmania.
9.32 supplied by M.R. Banks, University of Tasmania, from Banks, Cosgriff and Kemp, 1978.
9.33 P. Dalton, University of Tasmania.
9.34 from Weier, Stocking and Barbour, (1974), *Botany: an introduction to plant biology*, Wiley International Edition.
9.35 by A.K. Mills, supplied by P. Dalton, University of Tasmania.
9.38 from Spry and Banks (eds.) (1962), Journal of the Geological Society of Australia, Vol. 9, part 2.
9.40 from Burrett, C.F. and Martin, E.L. (eds.) (1989), *Geology and Mineral Resources of Tasmania*, Geological Society of Aust.
9.42 after Kemp, 1978.
9.54 after Orchiston, 1979.
9.56 by P. Murray from a Tasmanian Museum and Art Gallery poster.

Chapter one

Our changing earth

Andrew Scanlon and David Russell

Introduction

Geology is the study of our planet Earth. Modern geology began with the book, *The theory of the Earth,* by James Hutton (1726-1797). Hutton, a Scottish medical practitioner, stated that the Earth's form and substance are constantly changing and that the same processes that are operating now operated in the past.

In this book we will concentrate on the processes that occur on the Earth's surface. We will focus our attention on the results of these processes in the area that is now Tasmania.

Before launching into this study of Tasmania's landforms and geology we need to look briefly at some of the fundamentals of the science.

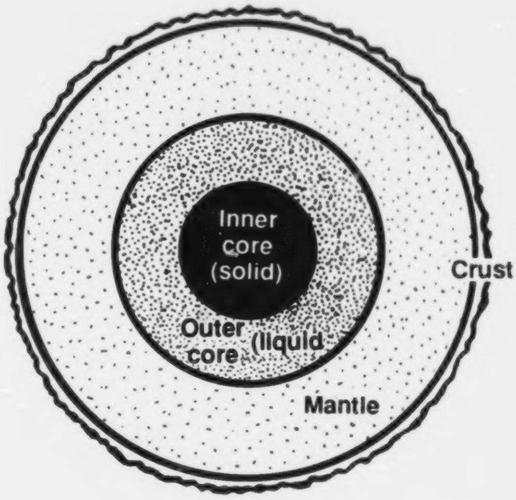
The Earth's origin and internal structure

The Earth formed approximately 4.6 billion years ago. There are many theories to explain its origin.

One theory is that the explosion of a nearby **supernova** triggered its formation. Dust and gas in space were compressed by the force of the explosion and a slowly spinning cloud of matter formed. The force of gravity caused most of the material to collect at the centre and form the Sun. Small whirlpools or eddies, trapped in the rotating cloud of gas and dust, also contracted under the force of gravity to form the planets — including our Earth.

The early Earth melted as particles were squashed together under the force of gravity. Two liquids separated out. One was made of molten iron and the other was mainly of oxygen and silicon. Just as oil floats on water, the less dense melt of oxygen / silicon floated on the iron. The Earth slowly cooled and a thin outer rocky **crust** formed.

From the study of earthquake vibrations we know that the Earth's interior is now made up of a number of zones (Fig. 1.1).



The Earth: a diameter of 12,750 km, a mass of 6.0 × 10^{21} tonnes, and an average density of 5.5 gm/cm^3

Fig. 1.1: The interior dimensions of the Earth.

The most dense materials (mainly iron) are in the solid **inner core**. The **outer core** (also iron) is liquid. The Earth's rotation causes movements in this liquid which in turn produce the Earth's magnetic field. Between the crust and outer core is a mainly solid **mantle**.

The Earth's rocks and minerals

The Earth's outer layer, or crust, is composed of **rocks** and **minerals**. Rocks are mixtures of minerals. Minerals are solid chemical compounds or elements.

The composition of minerals and rocks is dominated by a few chemical elements. Oxygen, silicon, aluminium, iron, magnesium and calcium are the most important (Fig. 1.2).

There are three main groups of rocks — **igneous, sedimentary** and **metamorphic**.

Element (symbol)	Percentage Weight of the Earth's Crust
Oxygen (O)	45.2
Silicon (Si)	27.2
Aluminium (Al)	8.0
Iron (Fe)	5.8
Calcium (Ca)	5.1
Magnesium (Mg)	2.8
Sodium (Na)	2.3
Potassium (K)	1.7
Titanium (Ti)	0.9
Others	1.0

Fig. 1.2: The most abundant elements in the continental crust.

Igneous rocks

Igneous rocks are the most abundant. There are three varieties of igneous rocks — **volcanic, hypabyssal** and **plutonic.**

Igneous rocks cool from a melt and consist of interlocking crystals. Melts form in parts of the upper mantle or lower crust. The less dense liquid in the melt rises through weak zones in the upper mantle or lower crust to collect in **batholiths, sills or dykes** in the middle and upper crust (see Fig. 1.3). Sometimes the liquid erupts onto the surface to form **volcanoes** and **lava flows.**

Volcanic rocks have very small crystals because they cool quickly. The other two varieties of igneous rocks, hypabyssal and plutonic, cool slowly beneath the surface. The hypabyssal rocks have medium crystals and the plutonic rocks have large crystals (about 1cm across).

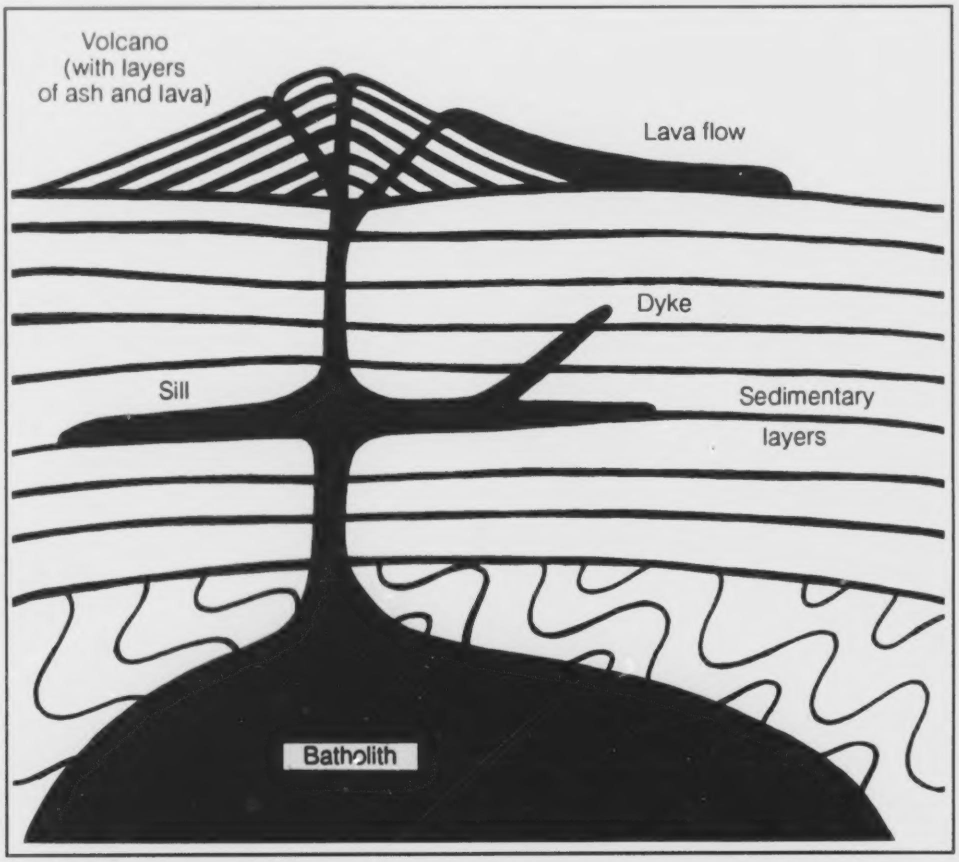


Fig. 1.3: The types of structures in which igneous rocks form.

Volcanic, hypabyssal and plutonic rocks can be divided into two groups — those that have mainly light-coloured minerals and those that have mainly dark-coloured minerals. Rhyolite and granite are examples of light-coloured igneous rocks. They come from melts that form in the crust under continents. Basalt, dolerite and gabbro are examples of dark-coloured igneous rocks. They come from melts that form in the upper mantle. Light-coloured igneous rocks are mainly composed of the minerals feldspar and quartz. Dark-coloured igneous rocks are mainly composed of the minerals feldspar, pyroxene and amphibole.

Sedimentary rocks

Sedimentary rocks form on the Earth's surface as a result of erosion and the movement of eroded materials to low areas. All rocks on the Earth's surface are exposed to chemical attack and mechanical change. Rocks are attacked chemically by materials which are dissolved in rainwater — carbon dioxide being the main agent. Pyroxenes, amphiboles and feldspars break down to form clays. Quartz remains largely unaffected.

Eroded materials are washed downstream and deposited in layers on flood plains, in lakes or in the sea. Over long periods of time the transported materials are buried and squashed as more sediments are deposited on top.

Erosion provides chemicals that take part in the process of sedimentary rock formation. Some of these chemicals dissolve in groundwater and eventually solidify around grains of eroded material to form a cement. Sedimentary rocks consist of clay and quartz, and cement minerals such as calcite (the calcium carbonate mineral that forms limestone) and iron oxide (rust).

Metamorphic rocks

The third group of rocks is called metamorphic, which means 'changed form'. Rocks that are deeper in the Earth's crust are under immense pressures and extreme temperatures. Over long periods of time, slow movements underground bend layers to produce folds. Under these conditions new minerals such as mica and garnet 'grow' in the solid rocks. This process is known as **regional metamorphism.** Change also results from the baking of rocks around a mass of molten material. This is known as **contact metamorphism.**

(i) Igneous Rocks

	Light	Dark
Volcanic	RHYOLITE	BASALT
Hypabyssal	DOLERITE	
Plutonic	GRANITE	GABBRO

(ii) Sedimentary Rocks

CONGLOMERATE — rounded pebbles
BRECCIA — angular pebbles
SANDSTONE — sand
MUDSTONE — mud (fine-grained)
SHALE — thin layers of mud
LIMESTONE — calcium carbonate
COAL — decayed plant matter

(iii) Metamorphic Rocks

Regional	Contact
SLATE	
SCHIST	
GNEISS	
QUARTZITE	QUARTZITE
MARBLE	MARBLE
	HORNFELS

Fig. 1.4: Types of rocks.

Change and geological time

Geologists believe the Earth to be about 4.6 billion (4,600,000,000 or 4.6 x 10^9) years old. During this vast expanse of time many changes have taken place. Some of these changes have taken place (and are taking place) rapidly; others are taking place very slowly (Fig. 1.5).

Our human life span is short and we tend to think with the poet of 'the everlasting hills'. But in fact, mountains vanish, coastlines change completely, and land appears where there was formerly sea. Some of these changes take place catastrophically (e.g. the eruption of a volcanic island), but most occur over long periods of time. The gradual wearing away of rocks by erosion, and the slow uplift of land associated with movements in the crust, have produced dramatic alterations to the face of the Earth.

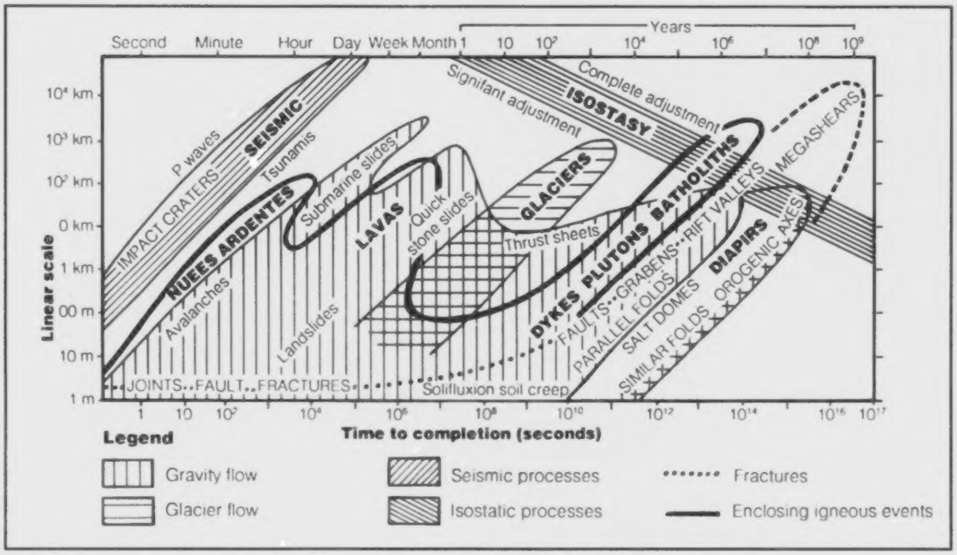


Fig. 1.5: A size-time model for some geological processes. (S.W. Carey, 1962).

Professor Carey's diagram (Fig.1.5) gives the duration and size range of a number of geological events. Earthquakes, volcanoes and avalanches are rapid events. Others, such as the flow of glaciers and the folding of rocks, are slower processes.

Measuring geological time

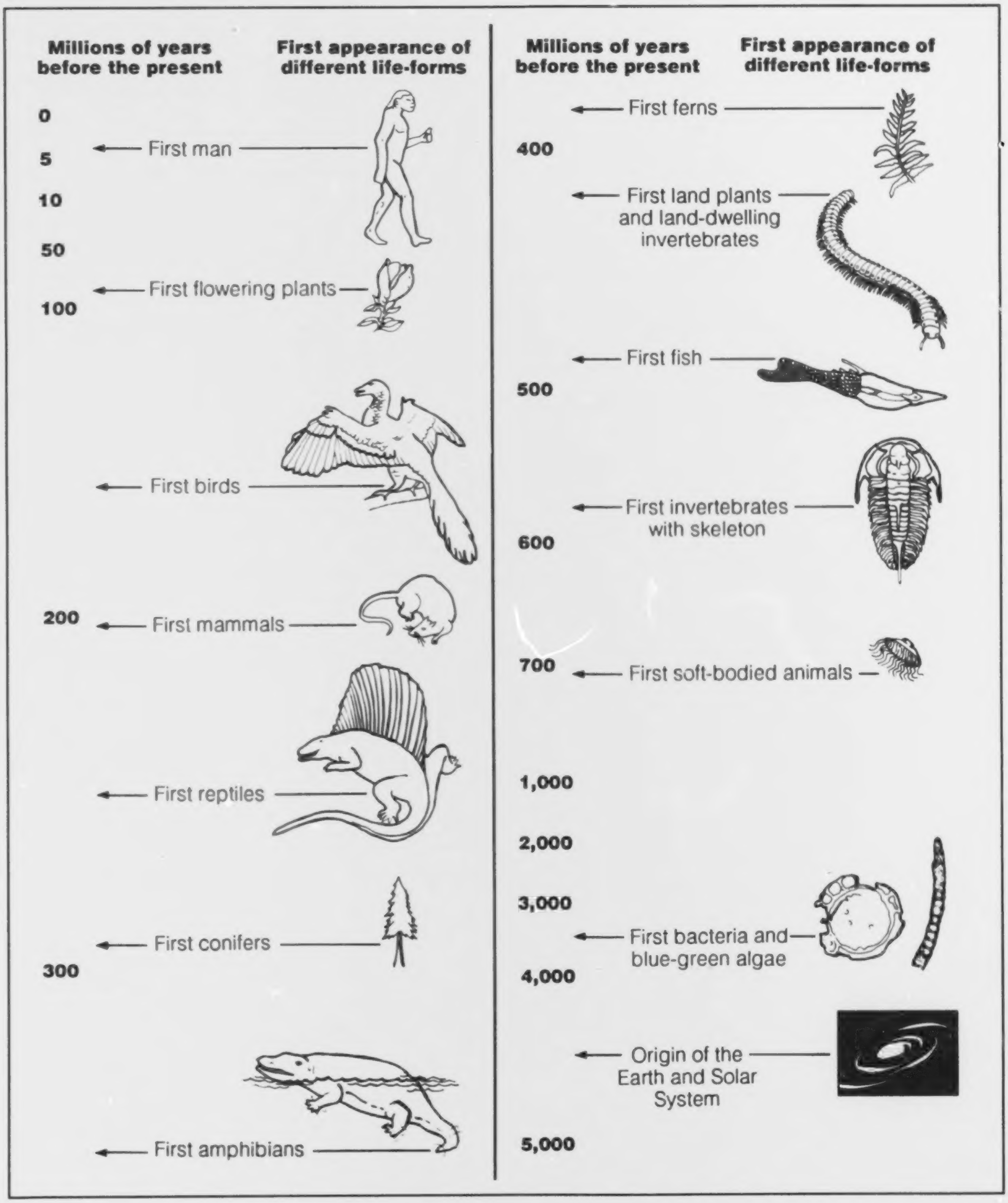
When studying changes to the Earth's surface we need ways of measuring geological time. We need to be able to work out when an event occurred. European geologists, working in the 18th and 19th centuries, pieced together a geological time-scale based on the types of **fossils** found in layers of sedimentary rock. Fossils are the imprints or remains of once-living creatures. Using the commonsense idea that layers of sedimentary rock near the bottom of a sequence are older than those near the top, these early geologists unravelled a changing pattern of life on Earth (Fig. 1.6). Modern geologists can use this now well-understood life sequence to give an age to the rocks in which fossils appear. Non-sedimentary rocks can be fitted into this age sequence by working out cross-cutting relationships. For example, an igneous dyke that cuts across a layer of sedimentary rocks is younger than the sedimentary layer.

The time-scale developed in the 18th and 19th centuries offers us a convenient method of labelling different periods of Earth's history (Fig. 1.7). In a similar way, most historians adopt convenient labels (for example, the Bronze Age and the Renaissance) to identify different periods of human history. Figure 1.7 also gives a date in years for the beginning of each geological Period.

PERIODS	**WHEN PERIOD BEGAN**
QUARTERNARY — the fourth division in an old time scale	2 million years ago
TERTIARY — the third division in an old time scale	65 million years
CRETACEOUS — named after chalk deposits in Europe	145 million years
JURASSIC — after a sequence of rocks in the Jura mountains of Switzerland	210 million years
TRIASSIC — named after a sequence of three distinct rock types in an area of Germany	250 million years
PERMIAN — rocks of this age were first studied in the Perm mountains of Russia	290 million years
CARBONIFEROUS — named after the European coal deposits of this age	365 million years
DEVONIAN — rocks of this age are found in Devonshire , England	415 million years
SILURIAN — after an ancient Welsh tribe, the Silures	440 million years
ORDOVICIAN — named after an ancient Welsh tribe, the Ordovices, in order to settle a dispute about which rocks were Cambrian and which were Silurian	510 million years
CAMBRIAN — after the Roman name for Wales, Cambria	570 million years
PRECAMBRIAN — before the Cambrian. Rocks of this age are difficult to divide because of the poor fossil record	4.5 billion years

Fig.1.7: An outline of the origin of the terms used in the geological time-scale.

Fig. 1.6: The first appearance of different life-forms.


Millions of years before the present
First appearance of different life-forms
0
5
First man
10
50
First flowering plants
100
First birds
200
First mammals
First reptiles
First conifers
300
First amphibians
Millions of years before the present
First appearance of different life-forms
First ferns
400
First land plants and land-dwelling invertebrates
First fish
500
First invertebrates with skeleton
600
700
First soft-bodied animals
1,000
2,000
3,000
First bacteria and blue-green algae
4,000
Origin of the Earth and Solar System
5,000

Putting numbers on the time-scale depends mainly on a process known as **radio-metric dating.** The radio-metric dating process is based on the fact that certain elements are unstable and lose particles from their central nucleus. This radioactive decay results in the formation of new elements. By calculating how much of a new (or daughter) element and how much of an original (or parent) element is present, a geologist can sometimes tell the age of the rock.

Figure 1.8 lists the different types of radiometric dating methods, as well as other ways of obtaining either accurate or very approximate dates for geological events.

DATING METHODS

Radiometric
- ^{14}C ^{14}N (organic materials up to 50,000 years old)
- ^{40}K ^{40}Ar
- ^{238}U ^{206}Pb
- ^{235}U ^{207}Pb
- ^{232}Th ^{208}Pb
- ^{87}Rb ^{87}Sr
- Fission tracks
- Thermoluminescence

Mainly igneous rocks

Palaeomagnetic
- polar reversals
- other variations

Biological
- growth rates (eg. lichens)
- growth layers (eg. tree rings)

Chemical
- amino acid racemization
- weathering rates
- identification of particular volcanic ash layers

Fig. 1.8: Dating methods.

The Earth's changing climate

When studying changes that have occurred on the Earth's surface, it is important to understand the nature of climate and climatic variation. Precipitation, wind speed, air temperature, and all the other variables which determine the climate of a particular region have a fundamental effect on the processes that shape our Earth.

Climate is the end-product of a multitude of interactions between several sub-systems — the atmosphere, oceans, land surface, ice and living creatures. It is the interactions between these sub-systems that make up our climate. Each sub-system is coupled in some way to the others such that changes in one sub-system may give rise to changes elsewhere (Fig. 1.9). There is widespread public concern about the possible effects of human activities on our climate. The depletion of the ozone layer and the 'greenhouse effect' are major environmental problems.

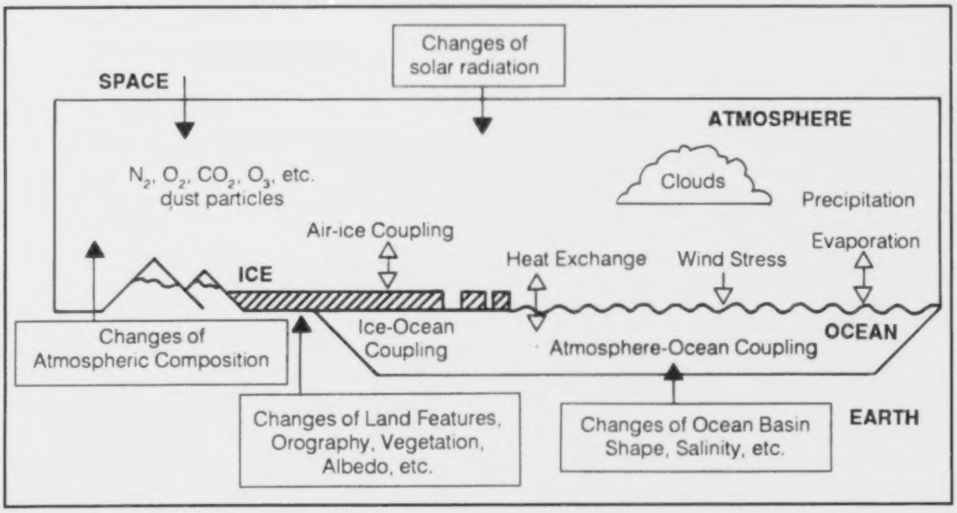

Changes of solar radiation
SPACE
ATMOSPHERE
N₂, O₂, CO₂, O₃, etc.
dust particles
Clouds
Precipitation
Air-ice Coupling
Evaporation
Heat Exchange
Wind Stress
ICE
OCEAN
Changes of Atmospheric Composition
Ice-Ocean Coupling
Atmosphere-Ocean Coupling
Changes of Land Features, Orography, Vegetation, Albedo, etc.
Changes of Ocean Basin Shape, Salinity, etc.
EARTH

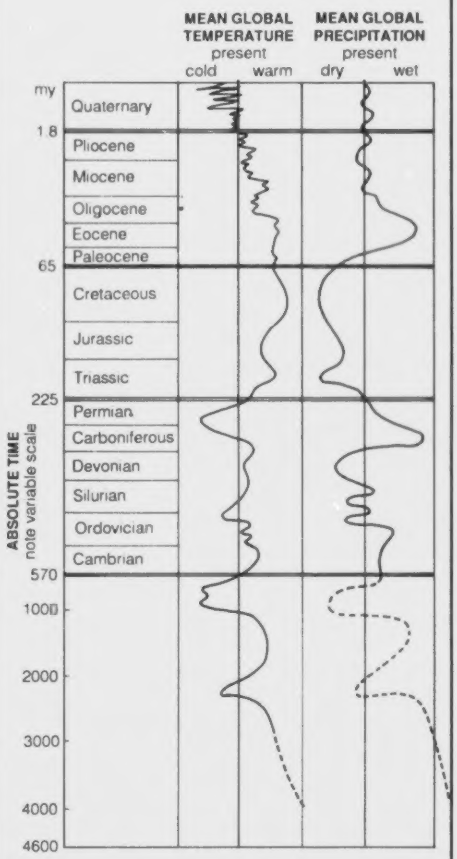
Fig. 1.9: Schematic diagram of major components of the climatic system. Feedbacks between various components play an important role in climate variations.

Behind the Scenery

Finding out what the Earth's climate was like millions of years ago is not an easy task. Geologists have to collect many pieces of evidence and put them together to build up a story. The further back in time we go, the more difficult it is to find the clues, and the less certain we can be about what actually happened.

Figure 1.10 gives a generalised picture of the temperature and precipitation history of the Earth. The time-scale is progressively expanded in younger time units and shows the evidence of short-term climatic variations. These short-term climatic variations cannot be so readily identified in earlier periods.

Fig. 1.10: Generalised temperature and precipitation history of the Earth.



The data to reconstruct past climates are obtained from a number of sources. It is impossible to detail all of these but a comprehensive list is provided in figure 1.11.

1. Glacial ice (Ice Cores)
- a) oxygen isotopes
- b) physical properties (eg ice fabric)
- c) trace element and microparticle concentrations

2. Marine sediments (ocean sediment cores)
- a) Organic sediments (accumulations of dead organisms)
  - i) oxygen isotopic composition
  - ii) abundance of plants and animals
  - iii) features showing adaptations to a particular climate
- b) Inorganic sediments
  - i) types of minerals
  - ii) surface texture of grains
  - iii) accumulation rates
  - iv) distribution of dust blown from the land and material deposited from melting icebergs
  - v) chemical variations

3. Terrestrial (land-based) features
- a) glacial deposits and evidence of glacial erosion
- b) evidence of freezing and thawing (periglacial features)
- c) erosional and depositional landforms along shorelines associated with the rise or fall of the land or the sea
- d) wind deposits (loess and sand dunes)
- e) lake deposits and erosional features
- f) ancient soils
- g) cave deposits (age and stable isotope composition)

4. Biological
- a) tree rings (width, density, stable isotope composition)
- b) pollen (type and abundance)
- c) large plant fossils (age and distribution)
- d) insects (type and abundance)
- e) modern population distribution (refuges and relict populations of plants and animals)

5. Historical (written records of various environmental indicators)

Fig. 1.11: Principal sources of data for Palaeoclimatic reconstructions.

Behind the Scenery

The Earth's climate has seen some quite dramatic changes over the last two or three million years. Figures 1.12 and 1.13 are landform and climate maps of Australia and New Guinea for 18,000 years ago and today.

The effect of a cooler climate 18,000 years ago can be readily seen in the extended coastline, areas covered by snow and ice, and the abundance of wind deposits in eastern Tasmania and what is now Bass Strait.

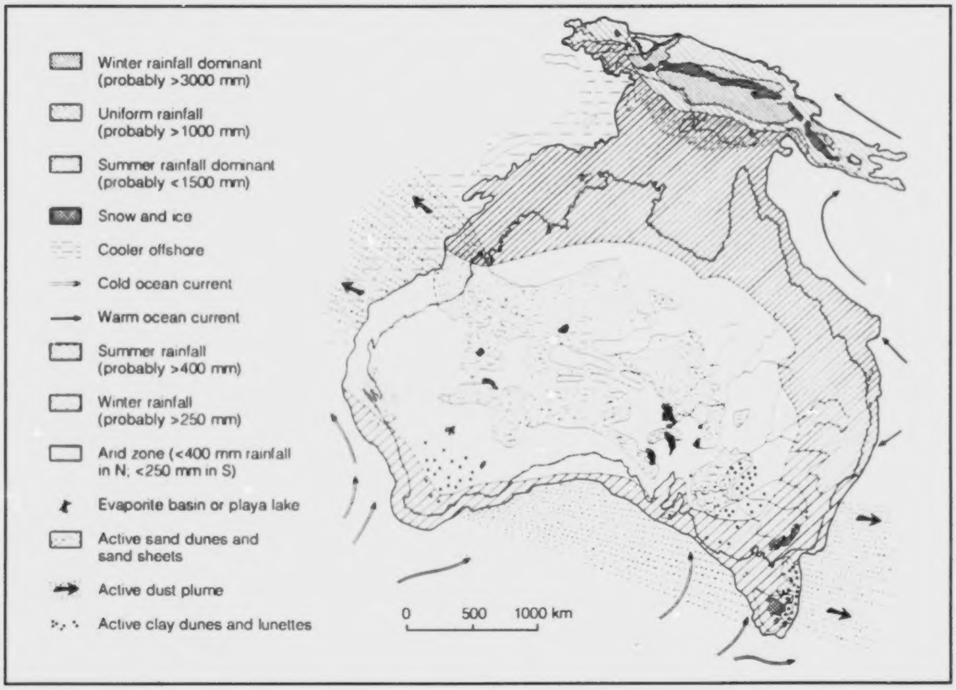

Winter rainfall dominant (probably >3000 mm)
Uniform rainfall (probably >1000 mm)
Summer rainfall dominant (probably <1500 mm)
Snow and ice
Cooler offshore
Cold ocean current
Warm ocean current
Summer rainfall (probably >400 mm)
Winter rainfall (probably >250 mm)
Arid zone (<400 mm rainfall in N; <250 mm in S)
Evaporite basin or playa lake
Active sand dunes and sand sheets
Active dust plume
Active clay dunes and lunettes
0 500 1000 km

Fig. 1.12: A landform — climate map of Australia/New Guinea 18,000 years ago.

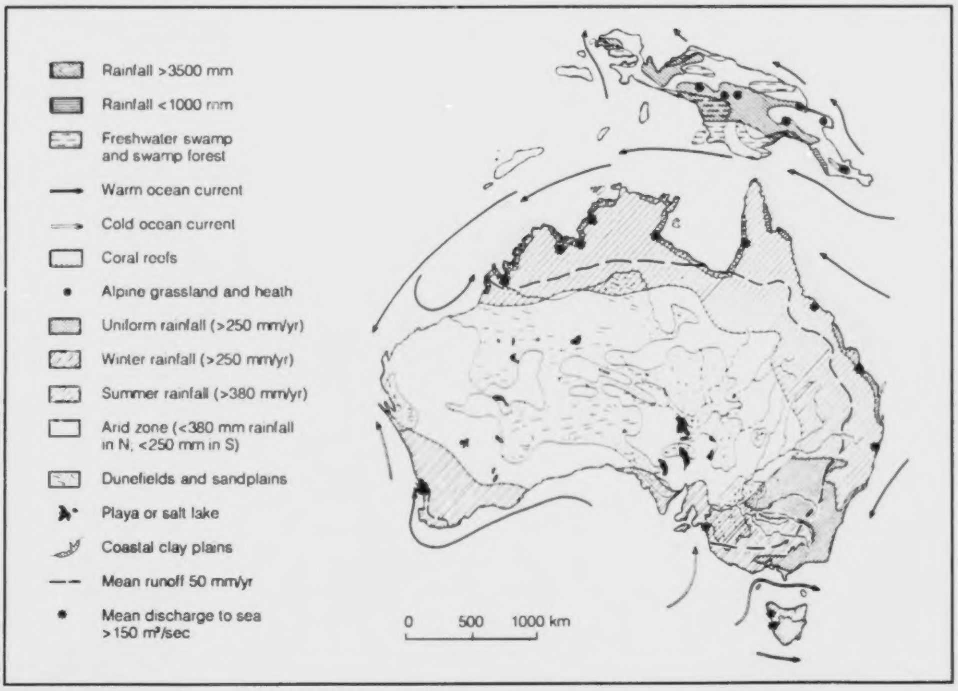

Rainfall >3500 mm
Rainfall <1000 mm
Freshwater swamp and swamp forest
Warm ocean current
Cold ocean current
Coral reefs
Alpine grassland and heath
Uniform rainfall (>250 mm/yr)
Winter rainfall (>250 mm/yr)
Summer rainfall (>380 mm/yr)
Arid zone (<380 mm rainfall in N, <250 mm in S)
Dunefields and sandplains
Playa or salt lake
Coastal clay plains
Mean runoff 50 mm/yr
Mean discharge to sea >150 m³/sec
0 500 1000 km

Fig. 1.13: A landform — climate map of Australia/New Guinea today.

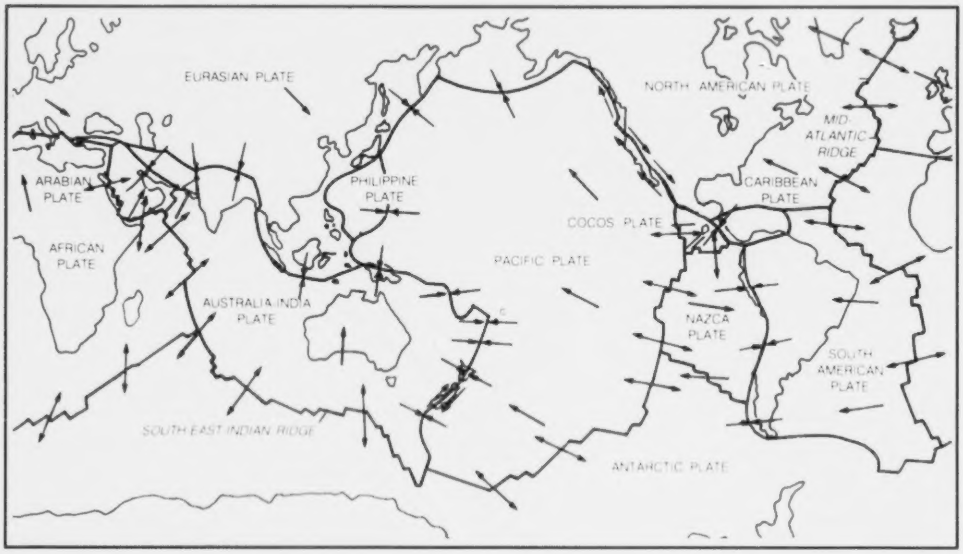

EURASIAN PLATE
NORTH AMERICAN PLATE
MID-ATLANTIC RIDGE
ARABIAN PLATE
PHILIPPINE PLATE
CARIBBEAN PLATE
COCOS PLATE
AFRICAN PLATE
PACIFIC PLATE
AUSTRALIA-INDIA PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
SOUTH EAST INDIAN RIDGE
ANTARCTIC PLATE

Fig. 1.14: Plates and their direction of movement.

Surface changes caused by processes within the Earth

The surface of the Earth is affected by both internal and external processes. During the vast expanse of geological time, forces operating beneath the Earth's surface have produced dramatic changes in the Earth's crust.

Most geologists now believe that the Earth's crust is divided into a series of **plates**. (Fig. 1.14). The boundaries between these plates constitute weak zones in the crust; and earthquakes and volcanoes often occur in such areas. The plates are thought to be riding piggy-back style on very slow movements occurring in the Earth's mantle. Arrows in figure 1.14 show the direction of these movements.

Figure 1.15 is a cross-section through South America and parts of the Pacific and Atlantic Oceans. Plates move apart where the slow mantle movements rise up and spread apart. Plates collide with one another where the movements come together and descend deeper into the mantle.

Shallow earthquakes, normal faults and basalt volcanoes are common where plates move apart. For example, the volcanoes found in the mid-Atlantic Ridge are a result of continental plates moving apart.

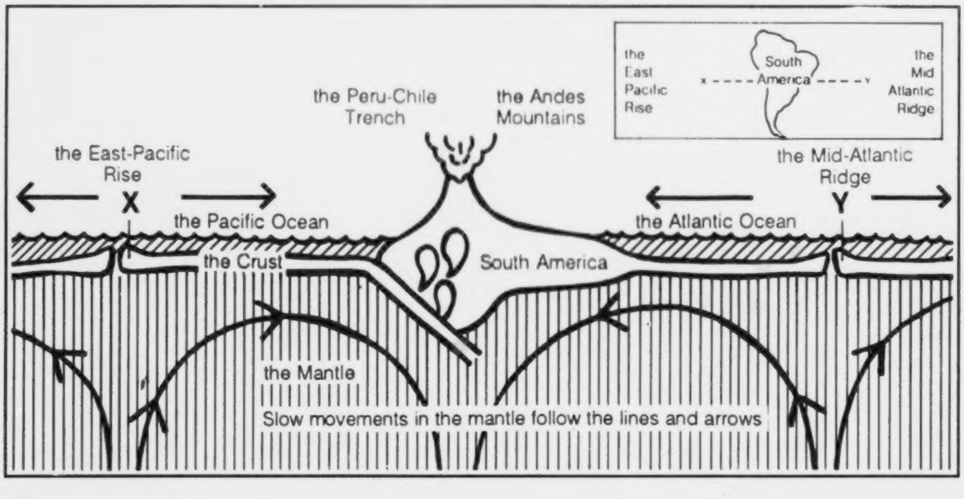

the East Pacific Rise
South America
the Mid Atlantic Ridge
the Peru-Chile Trench
the Andes Mountains
the East-Pacific Rise
X
the Pacific Ocean
the Crust
South America
the Atlantic Ocean
the Mid-Atlantic Ridge
Y
the Mantle
Slow movements in the mantle follow the lines and arrows

Fig. 1.15: An example of how plates of crust ride piggy-back on slow movements in the Earth's mantle.

Shallow earthquakes and strike-slip faults occur where plates slide past one another. (eg the San Andreas Fault).

Where plates collide with one another, shallow and deep earthquakes, reverse faults (Fig. 1.16), folds (Fig. 1.17), rhyolite volcanoes and intrusions of granite are common occurrences.

The Andes mountain chain and the Peru-Chile trench (where the ocean crust is being subducted beneath the continental crust) are good examples of zones where two plates are colliding.

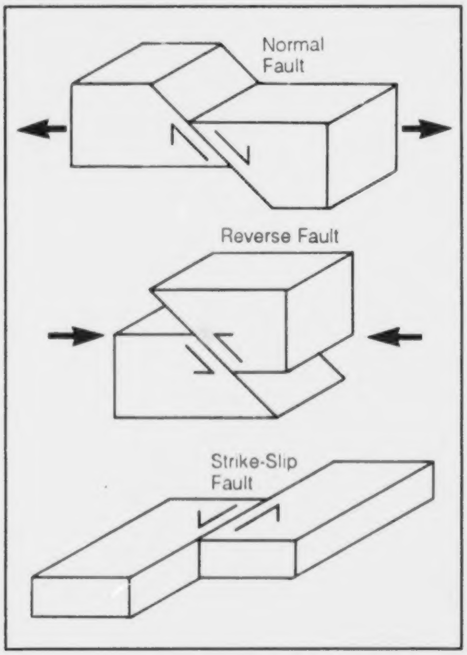


Fig. 1.16: Types of faults.

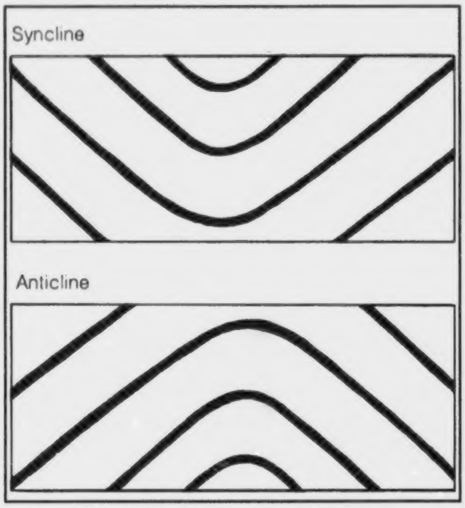


Fig. 1.17: Types of folds.

Continental drift

The movement of plates has produced a phenomenon known as **continental drift.** Large continents have broken up into smaller ones as new up-welling movements form in the mantle. Mantle movements have also brought smaller continents together, causing them to collide to form larger continents.

About 350 million years ago all the present continents were joined together in a giant super-continent called **Pangaea**. This split in two to form a northern super-continent, **Laurasia**, and a southern super-continent, **Gondwana**, (Fig. 1.18).

Since the **Jurassic**, about 180 million years ago, Gondwana has gradually split up to produce the patterns we can see today. For example, India has drifted off to collide with Asia, and the Himalayan mountains are the result. Similarly, Australia broke away from Antarctica about 50 million years ago and has been drifting slowly north ever since.

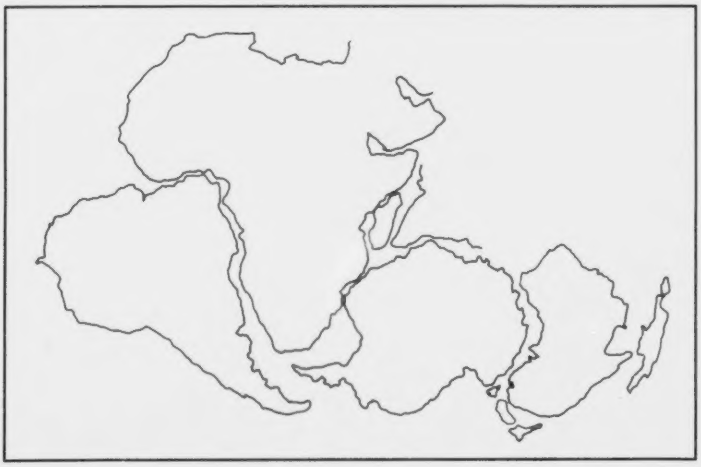


Fig. 1.18: Gondwana.

Summary

When trying to explain the geology and landforms of Tasmania we need to consider the processes, both internal and external, that have operated in the past. Tasmania was on the equator 500 million years ago and near the South Pole 100 million years ago (Fig. 1.19). During that time mountains have formed and been washed away, and the climate has changed from tropical to ice-bound. These changes, and the processes still operating today, have produced the pattern of geology and landforms that form the foundation of our scenery.

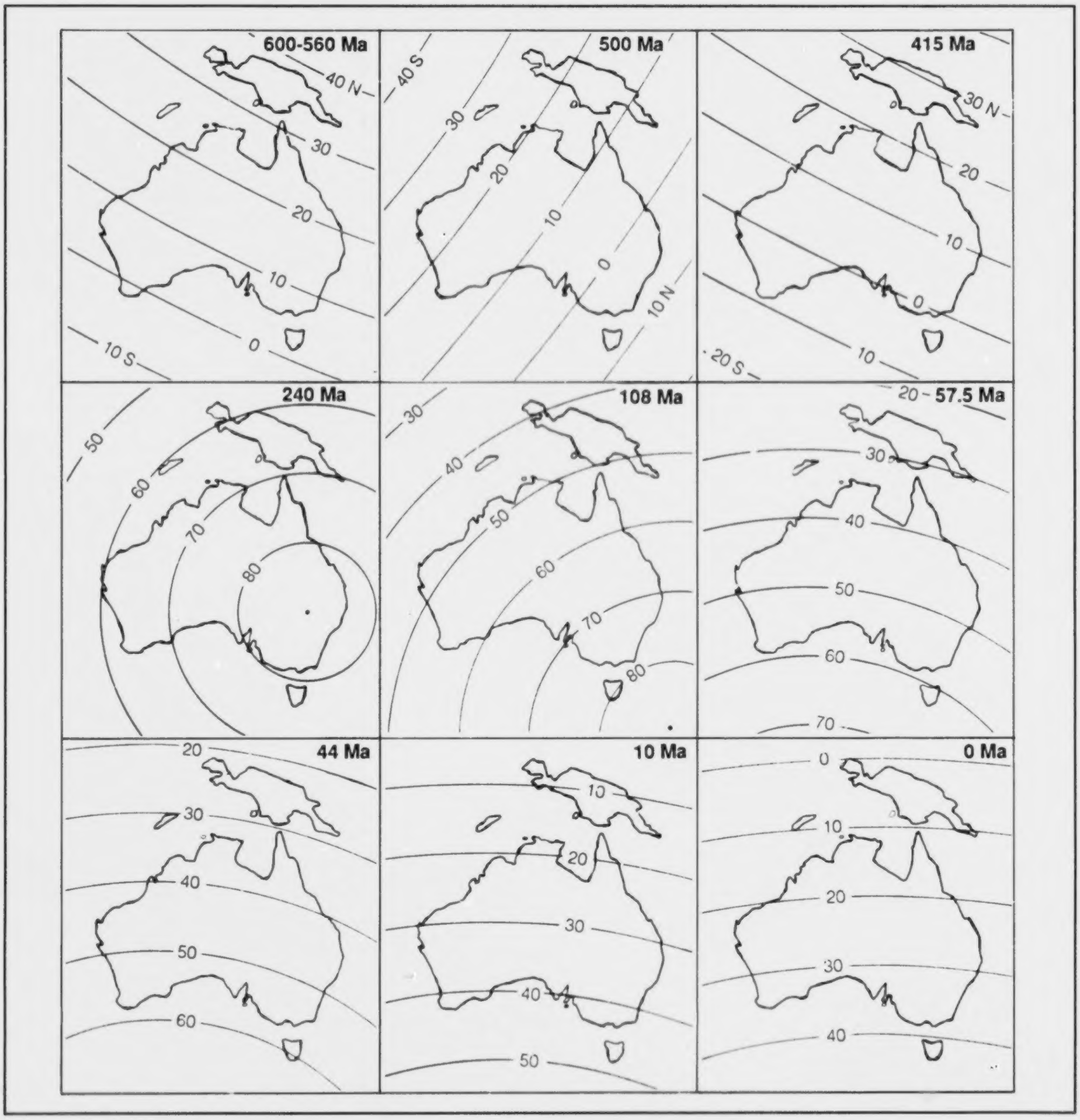

600-560 Ma
40 N
30
20
10
0
10 S
500 Ma
40 S
30
20
10
0
10 N
415 Ma
30 N
20
10
0
10
20 S
240 Ma
50
60
70
80
108 Ma
30
40
50
60
70
80
57.5 Ma
20
30
40
50
60
70
44 Ma
20
30
40
50
60
10 Ma
10
20
30
40
50
0 Ma
0
10
20
30
40

Fig. 1.19: The changing latitude of Australia during the last 600 million years (Ma = million years ago).

Weathering

Peter Manchester

Introduction

Have you ever looked at the names and dates on the headstones of the graves in one of the older cemeteries in Tasmania? If you have then you probably observed that many of the inscriptions are now indistinct. The headstones are 'weather-beaten'. Similarly, if you were to look at the Aboriginal engraving site at Mount Cameron West you would find only the blurred traces of patterns made by the earliest Tasmanians. An investigation of the penal buildings at Port Arthur and Maria Island would show you that many sections of those buildings show signs of crumbling.

If sandstone buildings and headstones of 'firm' rock have begun to crumble in less than two hundred years, what must happen to rock exposed to the atmosphere for thousands or even millions of years?

Such everyday observations remind us that rocks disintegrate and decay; that is, they are subject to change, they weather. The piles of rock debris at the feet of cliffs and scarps around Mount Wellington and other mountains are evidence of the process of weathering.

Weathering

Weathering is a collective term for the combined effects of all the processes that cause physical breakdown and all the reactions that bring about chemical transformation of rock materials.

The texture and composition of the rocks change as a result of exposure. The products produced as a result of weathering are more stable under the physical and chemical conditions that prevail at or near the Earth's surface.

Change or weathering takes place as soon as rocks are exposed to surface waters or the atmosphere. Cracks and crevices allow air and aqueous solutions to penetrate below the rocks' surface.

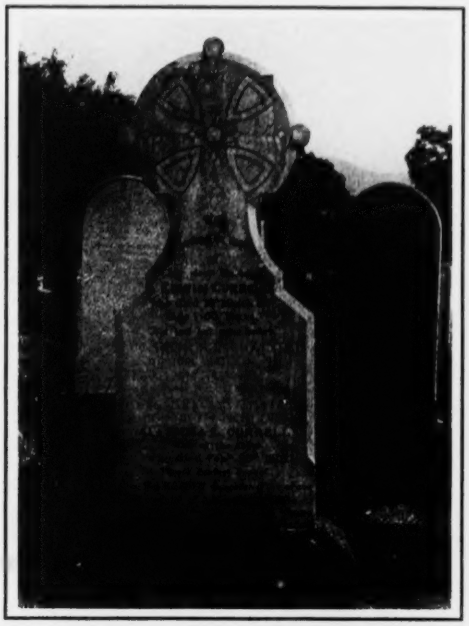


Fig. 2.1:
Headstones at Cornelian Bay.

Fig. 2.2:
This dolerite column stood near Blackmans Bay for several years, before yielding to the inevitable.

Weathering involves a diversity of processes and products. The variables that influence weathering can be summarised as:

- *rock materials;*
- the different *chemical and physical processes;* and
- *elapsed time.*

These variables influence the rate, type and end result of the weathering process.

The zone of weathering cannot be sharply delimited because it is a zone of interaction rather than a surface, and it extends down into the ground to whatever depth air and aqueous solutions penetrate.

Processes of weathering

Geologists usually make a distinction between what they term **chemical** weathering and **mechanical** or **physical** weathering. Chemical weathering can be thought of as the decomposition of rock materials. Mechanical or physical weathering can be regarded as the disintegration of rock materials. However it is important to understand that the two types of weathering work hand-in-hand and that their effects are inseparably blended. Disintegration, the mechanical break-up of rocks, exposes additional fresh surfaces to air and water. So disintegration aids decomposition, the chemical alteration of rock materials.

Examples of chemical weathering

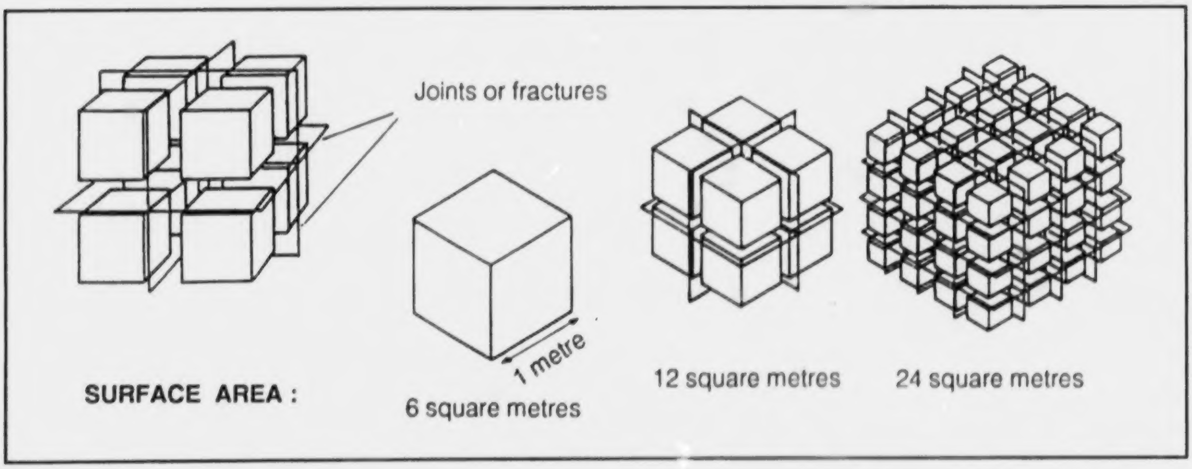
The granite road cuttings of the Upper Mersey Valley or the cuttings in and around the Pioneer-Gladstone area reveal the process of chemical weathering in action. In both cases we can observe a distinct upward gradation from fresh rock to highly weathered material .

Another example of what is predominantly chemical weathering can be found in the granite outcrops in the Tonganah area in Tasmania's North-East. If we look near the bottom of these outcrops we can see the cleavage surfaces of the grains of feldspar flashing brightly between the grains of quartz. But if we look higher up, the feldspar surfaces are lustreless and stained. And when we look near the very top of the outcrops we find that the feldspar now resembles a soft, earthy material that in no way resembles the feldspar to be found lower down the outcrop. Although, at the top of the outcrop, it is still possible to distinguish between the grains of quartz and the feldspar, it is clear that the feldspar has been completely changed.

Examples of mechanical or physical weathering

In contrast, the block streams surrounding the slopes of Mount Barrow provide an example of what is predominantly mechanical weathering. The minerals in the blocks are identical to the minerals in the adjacent dolerite bedrock — the minerals are quite as fresh as the minerals in the bedrock, or have been only slightly altered.

Fig. 2.3: Joints or fractures in a rock increase the surface area available for chemical weathering.



Because the blocks show little or no chemical change compared with the bedrock, we can conclude that the bedrock has been broken down mechanically.

As mentioned earlier, it is necessary to understand that mechanical weathering and chemical weathering work together — the mechanical break-up of rocks exposes additional surfaces to the action of air and water. Mechanical disintegration aids decomposition, the chemical alteration of rocks.

Two significant relationships are evident:

1. The mechanical subdivision of large blocks of rock into smaller blocks increases the surface area of rock exposed to further weathering.
2. The effectiveness of chemical reactions increases with increased surface area available for reaction.

In other words, the greater the exposed surface area of a rock particle, the more vulnerable it is to chemical attack.

Effect of bedding planes, fractures and joint planes

The rate and extent of weathering (both mechanical and chemical) is largely controlled by the distribution of structures such as bedding planes and joint planes within the rocks. Therefore, it is easily appreciated that a body of rock with a well-developed joint system will weather chemically much faster than one with no joints at all. Fault zones are even more effective in providing access for weathering agents.

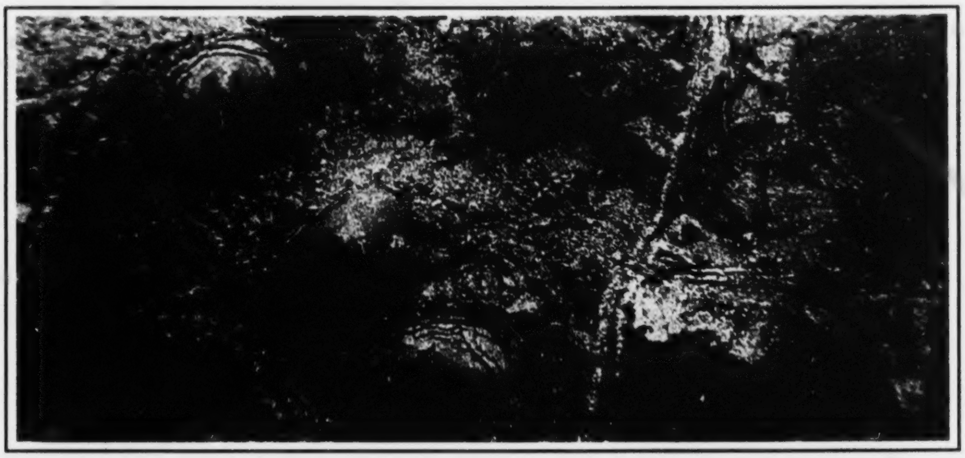
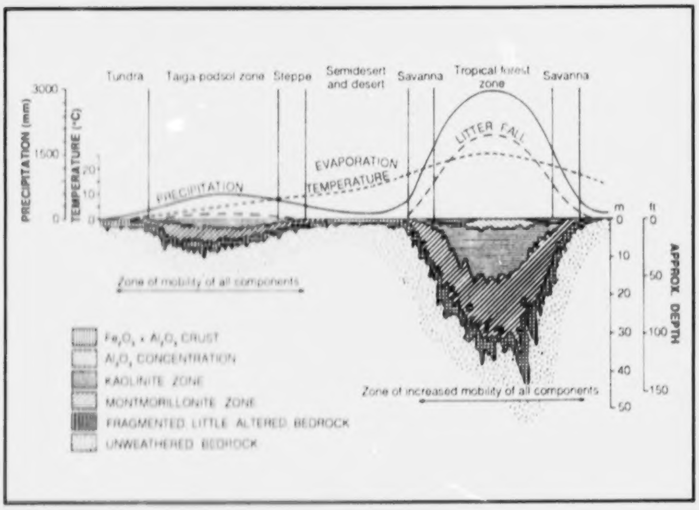


Fig. 2.4: Weathering of jointed dolerite, Brooker Highway, Hobart. Chemical attack is more effective where the joints intersect — hence the rounded or 'spheroidal' appearance of the weathered surface.

Chemical weathering: decomposition

The most active agents of chemical decomposition are water solutions, particularly those containing dissolved carbon dioxide and organic acids. In humid climates chemical weathering is a much more effective process than in dry environments.

Fig. 2.5: A schematic representation showing the depth of weathering in different climates. Note the fairly close relationship between precipitation and amount of weathering (kaolinite and montmorillonite are types of clays).


Tundra
Taiga-podsol zone
Steppe
Semidesert and desert
Savanna
Tropical forest zone
Savanna
PRECIPITATION (mm)
3000
1500
0
TEMPERATURE (°C)
20
10
0
PRECIPITATION
EVAPORATION
TEMPERATURE
LITTER FALL
m
0
10
20
30
40
50
ft
0
50
100
150
APPROX. DEPTH
Zone of mobility of all components
Zone of increased mobility of all components
$Fe_2O_3 + Al_2O_3$ CRUST
Al_2O_3 CONCENTRATION
KAOLINITE ZONE
MONTMORILLONITE ZONE
FRAGMENTED LITTLE ALTERED BEDROCK
UNWEATHERED BEDROCK

Another factor that influences the rate of chemical weathering is the type of minerals present in the rock. Figure 2.6 shows some of the more common minerals listed in order of their susceptibility to chemical attack by weathering agents.

Fig. 2.6: Chemical weathering of minerals.

Most easily weathered	Olivine	**Decreasing susceptibility to chemical weathering** ↓
	Pyroxene	
	Amphibole	
	Calcium-rich feldspar	
	Biotite	
Least easily weathered	Sodium and potassium-rich feldspars	
	Quartz	
	Muscovite	

Minerals such as olivine are less stable in surface environments than quartz. For example, on the coastlines in Northern Tasmania where a great deal of olivine-rich basalt is exposed, olivine is rare on the beach because it has been decomposed by the action of weathering agents. In contrast, quartz grains are abundant on the granite coastlines from Bicheno to Coles Bay, even for some distance off-shore. Quartz is simply more durable than olivine in the coastal environment.

Figure 2.7 shows an outcrop of granite speckled with dark tourmaline nodules which stand out in bold relief. The mineral tourmaline is more resistant than the feldspar in the granite.

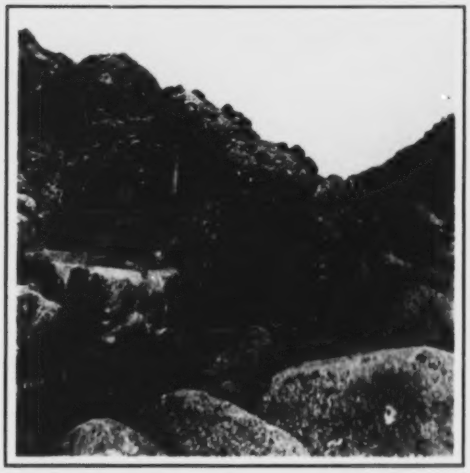


Fig. 2.7: Tourmaline nodules exposed in granite at Mount Heemskirk on Tasmania's West Coast.

The decomposition of rocks

Igneous rocks

Granite is a fairly resistant rock, being composed of more stable minerals such as quartz, biotite and feldspar. It weathers slowly to produce a rough surface. This is because the feldspars and biotite succumb first and the hard, chemically inert quartz stands out in relief. Potassium feldspar reacts with water containing dissolved carbon dioxide to produce a clay called kaolinite, colloidal silica, and potassium ions. As the minerals surrounding the quartz decompose, quartz gravel and sand accumulate in water courses and at the bases of the granite cliffs.

Dark-coloured igneous rocks such as basalt and dolerite weather more rapidly than granite because they contain minerals such as pyroxene and calcium feldspar which are susceptible to chemical attack. Both minerals weather to form clays. The iron in pyroxene forms oxides and hydroxides that give weathered basalt and dolerite their characteristic reddish and yellowish-brown colours.

Basalt is far less resistant than dolerite, despite their similar compositions. This is mainly because basalt rocks have a greater surface area exposed to the agents of weathering. Basalt often contains a large number of joints and fractures that were formed as the lava cooled on the Earth's surface. Gas-holes or vesicles are also common in basalt. Very deep weathering zones are associated with the rich basalt soils in north-western Tasmania.

Despite its similarity in composition, dolerite is more resistant than basalt because the rock fractures in dolerite are usually wider apart. Dolerite forms a resistant capping in many of the high areas around the State.

Sedimentary rocks

Sedimentary rocks vary in their degree of resistance to chemical weathering. Calcite, which is the main constituent of limestone, reacts with slightly acidic waters to produce soluble calcium bicarbonate. The calcium and bicarbonate ions are removed in solution:

$CaCO_{3(s)} + H^{+}_{(aq.)} \rightarrow Ca^{2+}_{(aq.)} + HCO_{3\ (aq.)}$

Tasmania's moist climate has led to the rapid removal of limestone as calcite is dissolved. Limestone generally outcrops in topographically low areas such as the Florentine Valley and Mole Creek. Large cave systems are common in these locations.

The degree of resistance to chemical attack exhibited by many sedimentary rocks depends on the amount and type of cement they contain and how closely the grains are squashed together. Where the grains are not well-cemented, small amounts of chemical decomposition can lead to a rapid breakdown of the rock. In humid climates, calcite cement would be more susceptible than iron oxide or silica cements.

Metamorphic rocks

In Tasmania's South West the topography provides a dramatic testimony to the effect of weathering on landforms. The interlocking quartz crystals of the metamorphic rock, quartzite, have protected it from weathering. Quartzite occupies many of the high areas in the South West (Fig. 2.9). The surrounding low areas are often underlain by the less resistant rock schist. Its flaky minerals are not as well held together and it quickly succumbs to attack by the agents of weathering.

Fig. 2.8: A view from the Strathgordon Road looking across the Florentine Valley to the Sawback Range. The jagged ridge is composed of resistant Ordovician conglomerate.

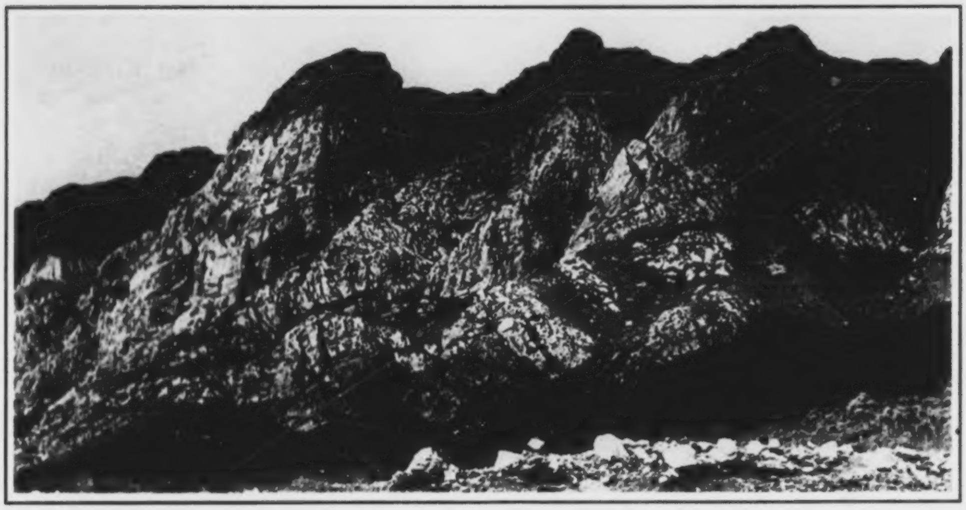


*Fig. 2.9:
The Sentinel Range is composed of resistant quartzite. The surrounding low areas are underlain by less resistant schists.*

Physical weathering –disintegration

Physical weathering involves the break-up of a rock without changes in composition of any of the minerals that make up the rock.

Despite the fact that weathering is usually considered under two distinct headings — chemical and physical — they do not act completely independently. The two groups of processes interact. **Heat** and **moisture** are the key factors in chemical weathering, and **stress** is the most important factor in the physical weathering of rocks.

Jointing

The cooling of an igneous body, the removal of water from some sediments as they compact, and movements in the Earth's crust — all of these produce stress in rocks. As the rocks react to stress, joints or fractures are a common result.

For example, when a deeply buried rock is uplifted and erosion removes material from above it, the confining pressure on the rock is greatly reduced. The relief from the burden of overlying material produces an expansion of the rock mass, and results in the formation of joints.

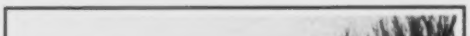


Fig. 2.10: The smoothly domed form of a granite outcrop in the Fingal area. The shape reflects the pattern of near-horizontal, sheet-type joints that developed in the granite as overburden was removed.

If we look at the near-horizontal joints developed in some of the granite monoliths of Tasmania's North East, we can see that the joints are approximately parallel to the land surface (See figure 2.10).This type of joint system seems to be a result of pressure reduction when the overburden was removed. There are further examples around South Mount Cameron and Mount Heemskirk on the West Coast. Granite outcrops in these areas show curved tabular sheets several metres thick.

Thermal expansion and contraction

Minerals differing in colour absorb heat at varying rates. When rocks such as granite or dolerite — with their different coloured minerals — have been exposed to the sun, internal stresses occur within the rock.

Furthermore, minerals not only differ in their rate of expansion — crystals of a given mineral also expand unequally in different directions. This means that some rocks are particularly susceptible to internal stresses caused by exposure to heat.

Frost action

The growth of ice crystals within a relatively confined space can exert enough pressure to cause rock disintegration. This is the same process that can burst water pipes in frosty weather. When water freezes it increases in volume by about 9% . If a fracture in rock is filled with water, the surface water is first to freeze as the temperature drops. The resulting ice crystals at the surface confine the water which is deeper in the crack. As these ice crystals grow, outward pressure leads to **frost wedging**. Where there are many small cracks, freezing may cause the rock to break up. This process is often called **frost shattering**. Frost shattering is most effective at high elevation where freezing and thawing are repeated over and over again.

The results of frost action can be seen on the slopes of Mount Arthur, Mount Barrow, Cradle Mountain and Mount La Perouse. The evidence comes in the form of loose angular fragments which cover the ground around the slopes of these and other mountains.

Frost wedging is of particular significance in glacial and periglacial (marginal to glaciers) conditions. Meltwater percolates into the joints and cracks, freezes, expands and pushes out blocks, some of which are of considerable size. Alpine peaks owe much of the detail of their jagged form to frost wedging. The northern and eastern slopes of many Tasmanian hillsides and mountains are covered with talus and scree which have been created as a result of frost wedging. The Western Tiers, Mount Wellington and the Thureau Hills all have scree slopes and talus.

Deflation of sandstone

Shallow, elongated caves and hollows may be observed in some of the Triassic sandstone outcrops found in Tasmania — particularly those outcrops next to rivers, the sea and poorly protected outcrops with a southerly aspect. These hollows have not been caused entirely by the action of the wind — the growth of salt crystals within the porous sandstones is also partly responsible. Groundwater with high salt concentrations evaporates from exposed surfaces and the crystal growth of the precipitated salt exerts pressure on the surrounding rock. This process forces apart and loosens sand grains from the parent rock. The sand grains may then be carried away by the wind, or by water after a rainstorm.

In some coastal outcrops, for example, in the Badger Head area and at Wybalena on Flinders Island, salt formation causes a feature called **honeycomb weathering.**

Organic activity

Plant roots find their way into openings in rocks and enlarge those openings as the plant grows. Tree and shrub roots can exert great force and assist the crumbling of the rock. The living matter of a plant is a gel that absorbs moisture and expands. Due to this expansion, tree roots can exert a pressure of up to maybe 100 kilograms per square centimetre. The effects of this can often be seen clearly on the edges of cliffs, as well as in road and railway cuttings.

Fig. 2.11: A block stream on Mount Wellington. The freezing and thawing of water in joints in the dolerite broke off large blocks of the rock. Continual freezing and thawing during the last Ice Age helped to move the blocks slowly downhill.

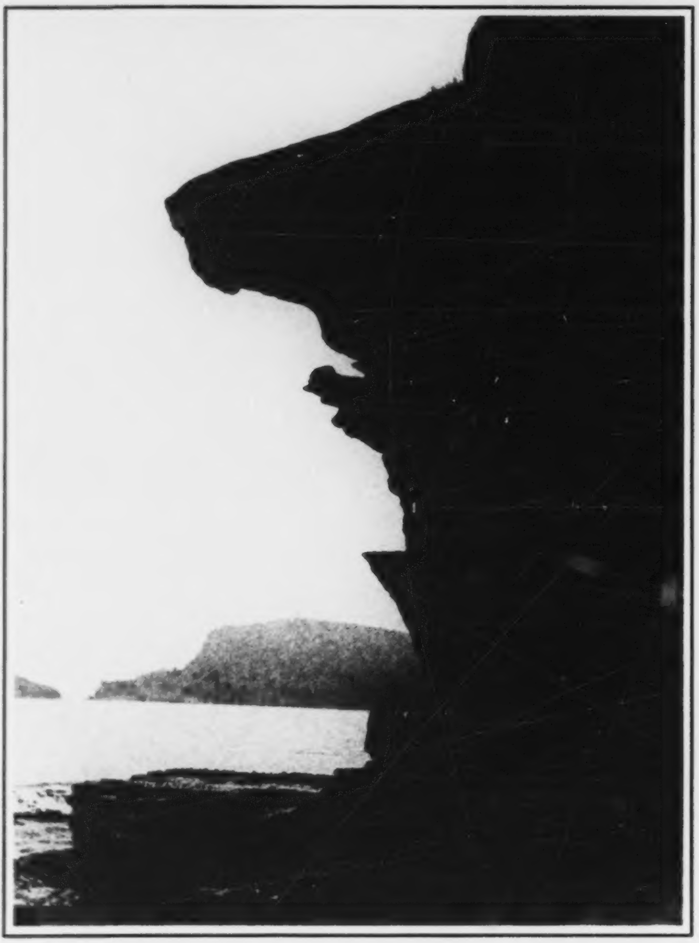


Fig. 2.12: The differential weathering of a coastal cliff of Triassic sandstone on Bruny Island. The growth of salt crystals on the surface is at least partly responsible for the honeycomb and other patterns visible on the cliff-face.

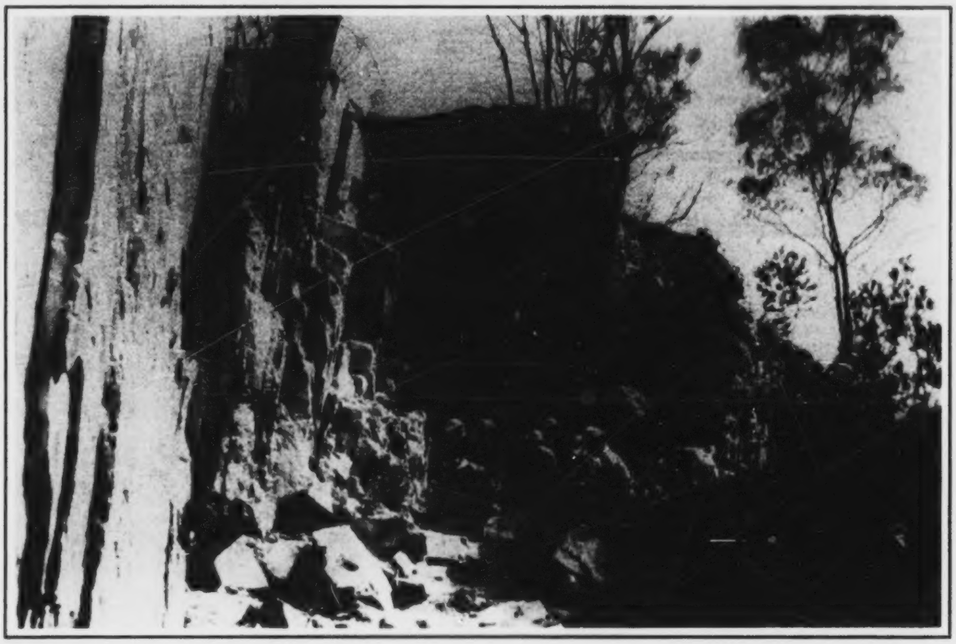


Fig. 2.13: This is a view of the old open-cut mine at Royal George in north-eastern Tasmania. Roots of trees have grown into joints in the granite and forced the joints apart.

Animal and human activity

Animals such as worms, rabbits and ants, burrow into the ground and increase the surface area exposed to weathering. Not only do they allow weathering to proceed more extensively, but they also prepare material for removal by rainwash and wind.

The activities of Europeans with axe and plough have had a great influence on weathering. The cutting of forests and the tilling of fields have mechanically opened up vast quantities of soil and subsoil to further weathering and more rapid erosion. Europeans have also introduced explosives and bulldozers which have exposed more rock to the agents of weathering.

Mechanical effects of wind, water and moving ice

Wind-carried sand grains serve as an effective abrasive for the scouring and polishing of rock surfaces.

The water and solid material carried by a river wear away fragments from its bed and its banks.

Moving ice is one of the most vigorous agents of rock breakdown. This is not because ice is a powerful agent on its own account but because it pushes and drags along fragments of rock which scour and abrade the rocks on the floor and walls of the glacial valley. A glacier acts as a huge rasp grinding up the rocks with which it comes into contact. Moving ice, then, is a very potent tool for the mechanical disintegration of rocks.

Although wind, running water and ice are primarily agents of erosion — that is, they help carry away rock debris and soil after the process of weathering has occurred — they do assist weathering by exposing more material to the physical and chemical agents of weathering and by further breaking down particles during their transportation.

Mass movement

The products of weathering are removed to lower areas in the landscape by the agents of erosion. The term **mass movement** is applied where this movement down slope involves relatively little movement between individual pieces in a body of fragments or blocks. Mass movement can take place either slowly or rapidly.

Creep is the slow, downhill movement of fragments and particles of rock under the influence of gravity (see Fig. 2.14).

More rapid mass movements include **landslides**, **mudflows** and **slumping** (see Fig. 2.15).

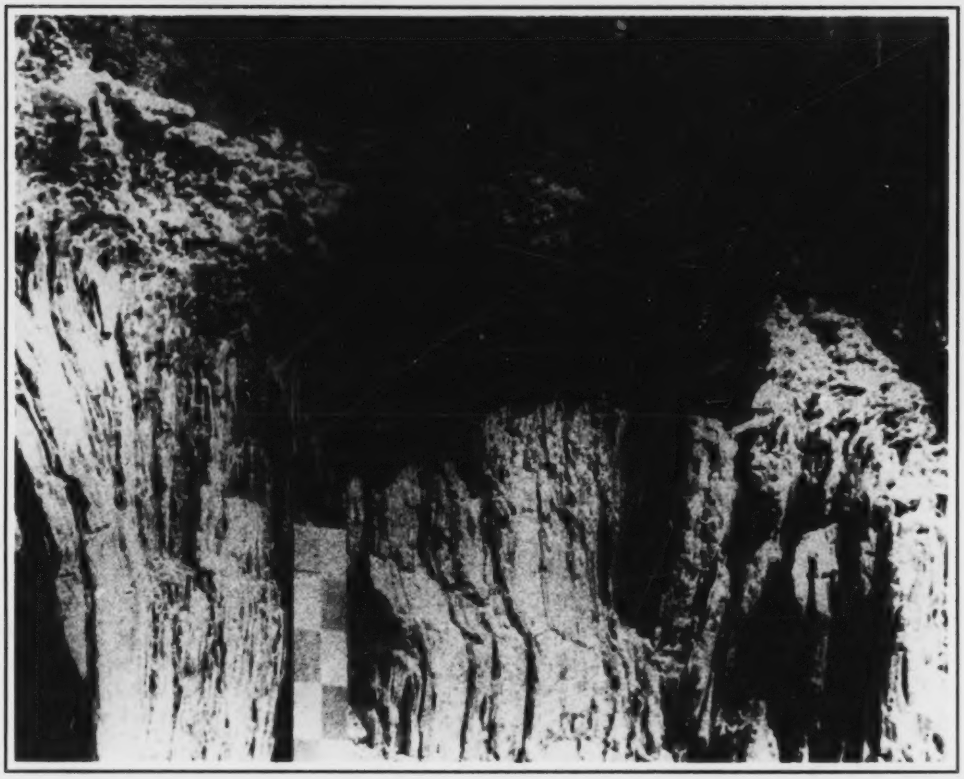


Fig. 2.14: Vertical beds of fine quartzite and micaceous layers showing downhill creep. Corinna Road, Savage River.

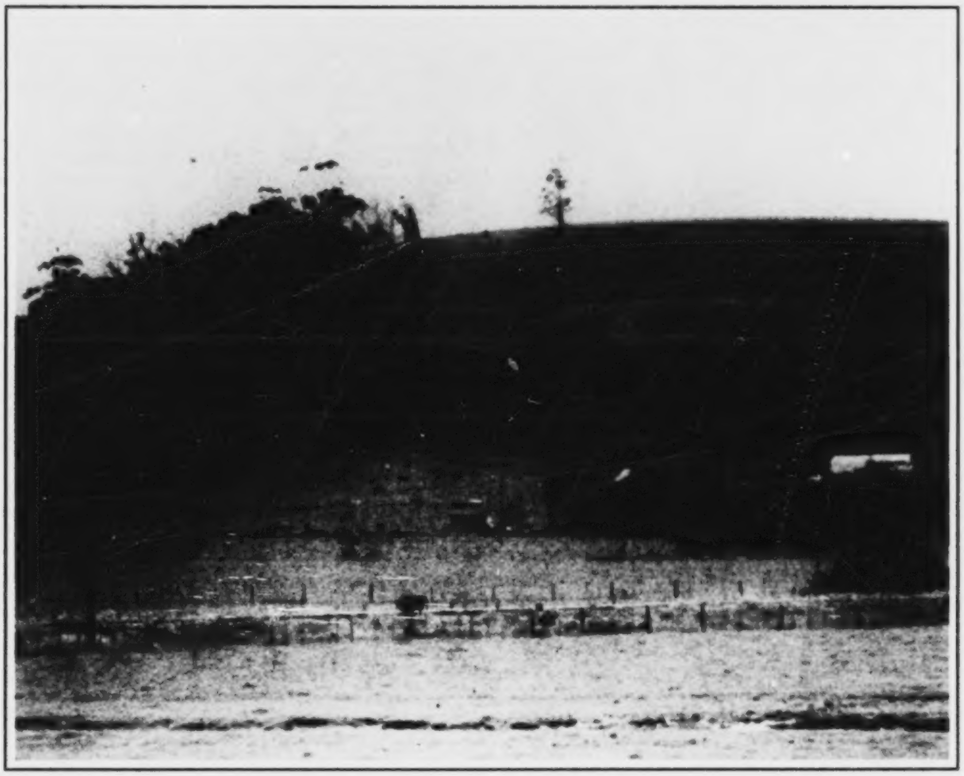


Fig. 2.15: View of a landslide on a basaltic hill near Lillico. The clearing of vegetation and heavy rainfall contributed to the instability of the deeply weathered basaltic soils.

Chapter three

Soils and soil erosion

Ruth Wilson

The link between soil types and scenery

On a trip through the Tasmanian countryside even the most casual observer cannot fail to notice important variations in the scenery. There are the mountains of the Western Tiers, the valleys of the Forth and Mersey Rivers, the flat plains around Longford and Cressy and the hilly land interspersed with flats, terraces and basins in the Southern Midlands — to mention but a few of those diverse features that are part of our landscape.

The landscape assumes many different shapes, but the natural vegetation also varies in type from region to region within Tasmania. Variations in the natural vegetation cover existed when the first Aborigines came to Tasmania. Since European settlement, pastoral and agricultural activities have taken a hand and have increased the differences in vegetation type to be found from one area to another.

To a large extent, the nature of the underlying soil in an area has determined whether or not that area has been taken over for farming. If the soil has been found suitable then the land will have been farmed. If the land has been found unsuitable then, for the most part, it will have been left in its virgin state. Tasmania is very dependent on the income and employment which is derived from agricultural production and therefore, where the soil is suitable for farming, then that land has been cleared. In that sense we can say that the appearance and land use of most areas in Tasmania is closely related to the nature of the soils to be found in those areas.

Soil: some definitions

Soil is formed from broken-down rock particles and organic material. Solid bedrock is generally covered with loose material which has been formed from the breakdown of that rock. Soil originating from the underlying bedrock in a particular area is described as **residual soil**.

In some places the bedrock is covered by material that has been formed from the breakdown of other rocks elsewhere. The material was transported to its present site by wind, water or ice. It is important to observe that in these cases it is not the soil which was transported — rather it was the rock particles that were moved. The soil was then developed from the transported rock particles. The soil-making process often proceeds rapidly on materials which have been transferred. For example, alluvial materials on river flood plains quickly develop into good soils.

A loose cover of material composed of decayed or decaying rock fragments stretches almost continuously over the Earth's surface. In places this loose cover may be 30 or more metres in thickness, whilst in hilly areas it may thin out to nothing so that solid bedrock outcrops at the surface.

Soil can be thought of as the surface layer of a mantle of rock waste in which physical, chemical and biological processes interact to produce a substance which maintains plant life directly and animal life indirectly.

Soils are composed of five main components or 'fractions':

- **mineral particles** — the inorganic fraction produced mainly from rocks as a result of weathering;
- **organic material** — dead and decaying plants, animals and animal products;
- **water** — the medium in which the nutrient elements are dissolved;
- **air** — fills the voids, if they are not filled with water, between the soil particles;
- **living organisms** — ranging in size from small animals to fungi, moulds, bacteria and viruses.

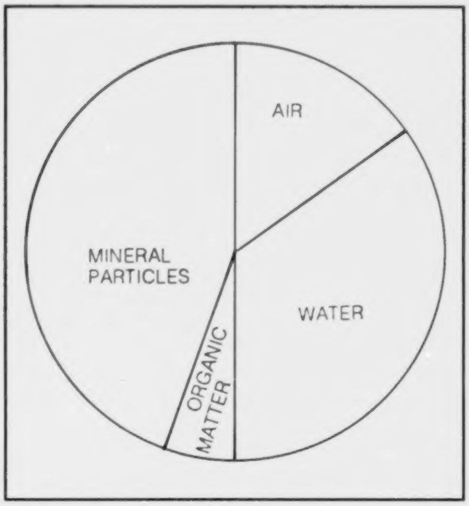


Fig. 3.1: The major soil fractions — the proportions vary in different soil types.

How are soils developed ?

Rock particles undergo a great deal of change before they become fertile soil. There are physical and chemical processes.

The ***physical processes*** of soil formation include the breaking up of rock particles by thermal expansion and contraction, and the abrasion of rock particles when they are carried by wind and water.

The ***chemical processes*** of soil formation require water and oxygen to be present. The chemical processes involve the breakdown or alteration of some minerals, and the subsequent formation of others by the recombination of the dissolved minerals. Chemical weathering can operate quite rapidly in the upper layers of a soil because these layers are often relatively warmer and contain more oxygen within the soil voids.

Living organisms have a marked effect on the rate at which soil is developed, mainly as a result of acidic secretions and waste products.

While a soil is developing, materials are added, transferred, transformed or lost from the soil system. Additions include organic material collecting on the soil surface. Transferrals include plant nutrients which are transferred to the soil surface by the action of plant roots; and many soil materials are brought to the surface by the activities of soil organisms. Transformations involve the chemical breakdown of minerals such as feldspars to produce secondary minerals such as clays.

The effect of rain on soils

As rain water soaks through the soil it dissolves soluble materials and carries particles of insoluble material both downslope and down through the soil. In some cases this material contributes to the formation of new soils downslope, but in other cases the effect is to remove those materials from the area and for them to be eventually washed out to sea. This process is called **leaching.**

One indication of the degree to which a soil has been leached is the presence or absence of calcium carbonate in the soil. Provided

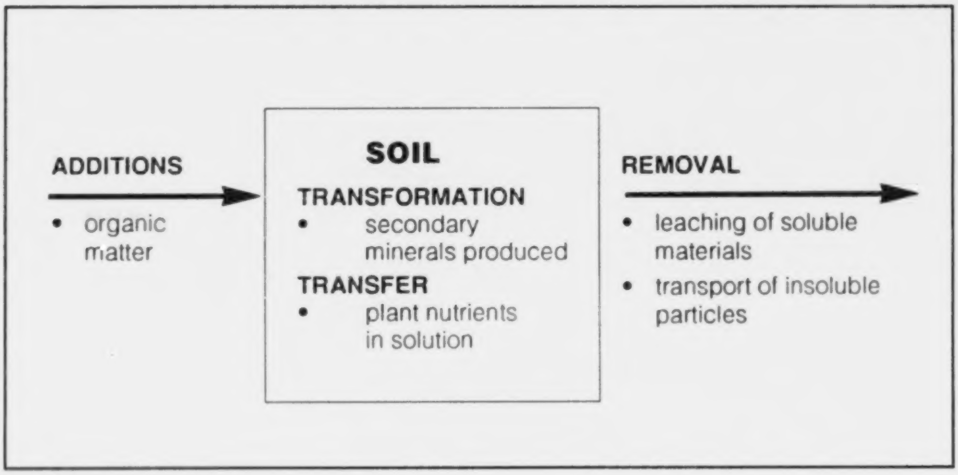

ADDITIONS
• organic matter
SOIL
TRANSFORMATION
• secondary minerals produced
TRANSFER
• plant nutrients in solution
REMOVAL
• leaching of soluble materials
• transport of insoluble particles

Fig. 3.2: Additions, transferrals, transformations and losses from the soil system.

that the parent rock is able to produce free carbonates (lime) as it weathers, lime may accumulate in the soil profile, particularly under arid conditions. However, some rocks, such as the Precambrian quartzites of Western Tasmania, are not capable of yielding soils rich in lime. The silica-rich parent rocks do not produce carbonates, and so the soils from such rocks will be deficient in calcium carbonate — even in the most arid environments.

Under conditions of more severe leaching, soils tend to become more acid. In agricultural practice, lime is frequently added to leached soils to counteract the tendency towards increasing acidity. Many commercially grown crops grow best in a slightly alkaline soil. In contrast, much of our native vegetation grows best in slightly acidic soils.

What determines soil type ?

Early students of soil formation recognized that five factors determine the type of soil which will develop in any particular situation. These factors are *parent rock type*, *climate*, *slope*, *organisms* and *time*.

Parent rock

It might be thought that the parent rock material would almost completely determine the type of soil produced, each rock yielding a distinctive type of soil — but this is not so. Areas of dolerite or basalt produce soils that are quite different, even though the bedrock is very similar. Climate and other factors are responsible for the differences in the types of soil that result from the same bedrock. However, residual soils reflect to some degree the nature of the parent rock from which they are developed. Thus in many instances it *is* possible to identify the underlying rocks by the types of soil occurring at the surface.

Climate

Climate is often a dominant factor in determining the type of soil because it controls the amount of water available for leaching. It is possible to relate particular types of soil to the climatic zones in which they were formed. *Temperature* appears to influence the effectiveness of weathering and the depth of the soil which is produced.

Aspect is also an important factor. Soils on the eastern side of a hill frequently vary from those found on the western slopes of a hill.

Slope

The slope of the land surface always has a bearing on soil development because slope has a direct influence on drainage and leaching. The soil on top of a hill is frequently different from the soil on the lower slopes of the same hill, even when only one rock type is present.

Organisms

Organisms include plants and animals living on the soil as well as fungi, bacteria, and other micro-organisms living within the soil. Except where large amounts of mineral matter are blown onto the surface of the soil by wind, or are washed onto it by water, plants are the principal source of additional material for the top soil layer. Plants draw nutrients towards the surface, and these are left there when the plants die. The dead plants also leave organic material which eventually becomes humus.

A fertile soil requires humus, various mineral salts in trace proportions, space for the accumulation of water and air, and space for the free development of plant root.

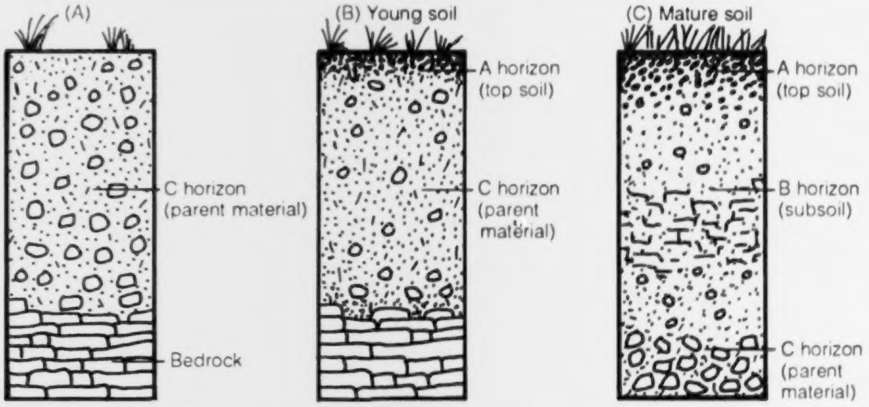
Time

Time influences soil formation because it determines for how long the other factors have been operating. The age of the soil is quite distinct from the age of the parent rock. Except in unusual circumstances, a soil of recent origin will differ from one that has been developing for tens of thousands of years.

Succession

Ordinarily, soil development is a slow process and little change would be expected within the span of a human life-time.

With some parent rock material it is difficult to imagine that soil will ever develop from it, except over an immense period of time. But consider the following proposition for a pure silica sand. Water could move up through the sand by capillary action and evaporate below the surface, depositing its soluble minerals in the silica sand. Some plants could then grow and leave their organic remains, the dust they had collected, and the salts that they had extracted from the water. Other plants could then grow, and animal life would gradually flourish in the soil. Given enough time, a mature soil could develop in spite of the unpromising nature of the original material. This process is referred to as **succession**. The process frequently occurs on the bare rock surfaces of new volcanic islands and can eventually alter a seemingly inhospitable environment.



HOW SOIL IS FORMED: (A) Parent material overlies rock from which it developed.
(B) Decades later, young soil forms at the top as plant growth (grass) increases.
(C) Topsoil deepens. Note the horizon or boundary between topsoil, subsoil, and parent material.

Fig. 3.3: How soil is formed.

Soil profiles

The movement of soil constituents, the accumulation of organic matter, and the differential weathering as soil formation proceeds, result in the development of layers or horizons within the soil. A **soil profile** is a vertical section through a set of such horizons, one below the other, from the surface down to the weathering rock. The study of soil profiles and the processes of their formation is the science of **pedology.**

Soil profiles, weathered rock and relatively unweathered rock may be seen one upon the other in cuttings, and near the edge of quarries.

There are three major zones or **horizons** in a typical soil profile:

- The **lower horizon** or **'C' horizon** is a zone of partially disintegrated and decomposed rock fragments. Within this zone some of the minerals of the original bedrock are unchanged, but others have been altered into new minerals by the weathering process.

In the case of a residual soil, below the 'C' horizon there is solid unweathered bedrock. This would not apply to a profile developed in alluvium or other transported material. Underneath this transported type of material one might find older soils that have been covered.

- The **'B' horizon** immediately above the 'C' horizon contains fewer unaltered minerals from the original rock. Very resistant minerals such as quartz are still recognisable but weathering has been more intensive than in the underlying 'C' horizon.

Of course some soluble materials will have been washed away, but in moist areas the 'B' horizon may contain clay and iron oxides which have been deposited by downward-moving ground water. If the climate is drier, there may be deposits of gypsum and other soluble minerals — because these are deposited when water evaporates. It is common in

Tasmania to find deposits of the carbonates of calcium and magnesium. The 'B' horizon is often called the **illuvial zone** or the **zone of accumulation**.

- The uppermost or **'A' horizon** is the one which receives the main attention from agriculturalists. Much of the clay, iron oxides and salts accumulated in the B horizon have been derived from this A horizon. The plant and animal life that dies and decays on the surface means that most organic matter accumulates in the 'A' horizon.

Each of the horizons develop from the bedrock which they overlie. Soil formation is continuous and soil profiles rarely reach a static condition. Over a long period of time the A horizon may encroach into the B, the B into the C and the C into the underlying rock so that the profile gradually deepens. On the other hand, erosion may cause the gradual removal of the surface of the A horizon; or in catastrophic circumstances the whole profile may suddenly be removed. When a profile appears to be approaching a static condition it is said to be **mature**.

Soil texture

As stated earlier, soil consists of mineral particles and organic material. The mineral particles also come in different sizes. A soil's **texture** is a reflection of the relative proportions of mineral particles of different sizes and of the proportion of humus contained in the soil.

For example, when the bulk of the soil consists of relatively coarse particles, the soil is said to have a **sandy** texture; whereas a soil composed mainly of fine particles is called a **clay**. **Peats** are soils consisting largely of humus.

Loam is a term used repeatedly in connection with soils. It does not represent a genetic type of soil but refers to texture. Classification according to texture can be done with the help of a diagram similar to the one shown in figure 3.4.

As can be seen in the diagram, loams consist of between 5-15% organic matter and rather more silt than sand, plus some clay. Unlike clay, loam does not become sticky when moist, and nor does it dry out as quickly as sand.

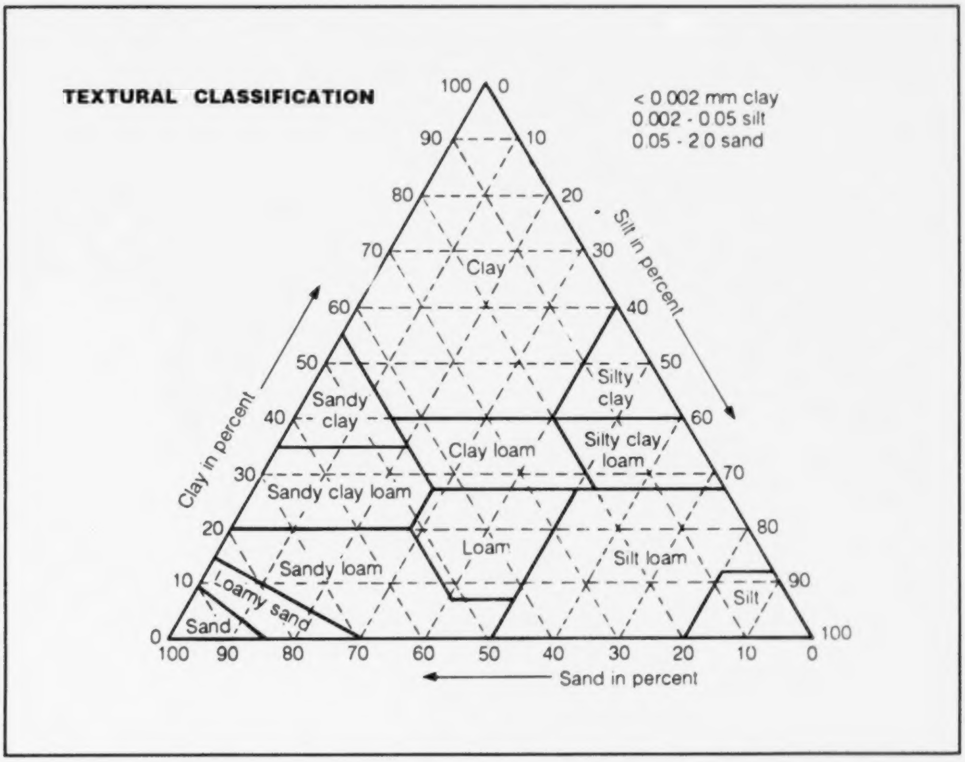
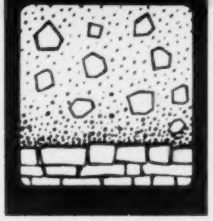

TEXTURAL CLASSIFICATION
< 0.002 mm clay
0.002 - 0.05 silt
0.05 - 2.0 sand
Clay in percent
Silt in percent
Sand in percent
100
90
80
70
60
50
40
30
20
10
0
Clay
Silty clay
Sandy clay
Clay loam
Silty clay loam
Sandy clay loam
Loam
Silt loam
Sandy loam
Loamy sand
Sand
Silt

Fig. 3.4:
U.S. Department of Agriculture textural classification chart.



Soil types in Tasmania

Tasmania's climate usually results in soils that are strongly leached. In many parts of Tasmania the parent rock type is rich in silica so the material which is derived from this by weathering tends to form **podzols** and **podzolic soils.**

Podzols

The term podzol refers to a soil with a particular kind of soil profile. In a podzol soil profile the organic surface horizon is underlain by the strongly leached and therefore light-coloured A horizon. The B horizon is enriched with organic matter and/or iron oxide which have been leached down into the B horizon.

The podzols are usually developed in coastal areas, on sand sheets and dunes which have blown inland. The soils are strongly acid in character because of the extensive leaching they have experienced.

These podzol soils can be readily and cheaply cleared of the sparse heath and scrub vegetation which covers them. In many coastal areas, for example near Bridport, such lands have been sown to pasture.

Podzolic soils

Podzolic soils are far more extensive in Tasmania than podzols. They are similar to podzols in that they have a leached A horizon, but clay accumulates in the B horizon rather than organic material or iron.

There are several types of podzolic soils to be found in Tasmania.

Lateritic podzolic soils

Lateritic podzolic soils are found mainly in the Midlands Graben. These podzolic soils have either a sandy or a loamy A horizon. They occupy the remnants of old erosion surfaces and high river terraces.

The soils with the sandy A horizon often contain large amounts of ironstone gravel in the A horizon and rest on strongly weathered kaolinite clays which are often highly coloured. Until recently these sandy lateritic podzolic soils only supported native pastures and were utilised as rough grazing, but some areas are now being converted to 'improved' pasture.

The soils with the loamy A horizon were important in the early settlement of the Midlands area. They were cleared and sown with cereal crops. These soils are deficient in molybdenum, but when this is corrected they can be sown to pasture for extensive grazing by sheep.

Yellow podzolic soils

In areas with a predominance of siliceous rock, weathering may well yield some clay and yellow podzolic soils. These podzolic soils have a greyish A horizon and a yellowish, often mottled, B horizon.

These soils often support a heavy sclerophyll timber cover. In the past this kind of land has been left uncleared, but it is now being cleared for pasture development and for woodchip production.

Grey-brown podzolic soils

These soils tend to be restricted to dolerite in moderately wet (650-1,000 mm per annum) areas below 600 metres. They are characterized as having a sandy loam A horizon, often with ferruginous concretions and a B clay horizon. These soils yield timber in quantity and are used for grazing. However the steep slopes and the presence of boulders and fragments of dolerite inhibit agriculture.

Skeletal soils

Much of Tasmania is unsuitable for cultivation and grazing. Where there are steep slopes, particularly on quartzite and granite, soils tend to be shallow and sandy and strongly leached — with abundant rock fragments and some humus. These soils rarely develop a soil profile. Such soils are referred to as skeletal soils and tend to be found in the west, south, and north east of Tasmania.

Krasnozems

Krasnozems are another group of highly leached soils. They are found where dark-coloured, igneous rocks such as dolerite and basalt are subjected to high rainfall. The annual rainfall required for them to develop is about 750 mm for basalt and 1,000 mm for dolerite.

The krasnozems are typically developed on the basalt flows of the North West coast and in the North East around Scottsdale. There are also lateritic krasnozems at Campbell Town, although rainfall totals are less than in other krasnozem areas of Tasmania. These soils at Campbell Town are probably related to past climatic conditions.

Krasnozems are brown or red due to the high proportion of iron minerals in the clays. The change from the A to B horizon is always gradual. Krasnozems are typically deep, well-drained and friable. They would have originally supported a heavy forest vegetation. The soils near the coast are often the reddest in colour, but with increasing elevation and rainfall and decreasing temperature inland, the red colour gives way to black and brown. In addition, soil acidity increases away from the coast.

While krasnozems are good for farming they are not highly fertile. **Productivity** can only be maintained with the addition of fertilizers, particularly superphosphate and ammonium sulfate.

Areas with krasnozem soils are used for dairying and for growing vegetables such as peas and potatoes. The relatively steep slopes found in these soil areas make these areas liable to soil erosion, particularly after heavy rain.

Black earths, brown earths and prairie soils

In the relatively dry valleys of the Midlands and the South East, where rainfall is below 650 mm, black earths, brown earths and prairie soils are developed on basalt and dolerite. The black and brown earths are generally slightly acid to neutral at the surface, and neutral to alkaline below.

Although developed on basalt and dolerite, these soils contrast strongly with krasnozem development elsewhere in Tasmania.

> **Black earths** are relatively shallow and many have deposits of carbonate in the lower horizons. They are often hard and lumpy when wet and are more difficult to cultivate than the krasnozems. Black earths are typical around Richmond, Campania and Sorell.
>
> **Brown earths** are more extensive than black earths. They are stony and shallow and are often located on steep slopes. Therefore they are cultivated only infrequently. They are used mainly for sheep grazing. Typical localities for this soil type occur around Brighton, Kempton and Tunbridge.
>
> **Prairie soils** are mostly found on small but widely distributed patches of basalt — often in a complex relationship with brown and black earths. The terrain is less steep and, although the soils are stony, they are stable.

Calcareous coastal sands and terra rossa soils

> The **calcareous coastal sands** are the grey alkaline sands containing shells which have blown inland from the west-facing beaches of King and Flinders Islands.
>
> The **terra rossa soils** are the reddish brown, slightly acid soils which are formed on the older dunes further inland.

Acid swamp soil and alkaline fen soils

These highly organic soils are found at low elevation in areas of former swamp. They occur mainly in North West Tasmania and on King and Flinders Islands. Montagu Swamp near Smithton is the largest of these swamp areas and has highly acidic soil. In contrast, the nearby Mowbray Swamp has some alkaline soil because of the underlying presence of the Smithton dolomite. When drained these soils can be made highly productive, particularly for dairying.

Alpine humus soils

These yellow-brown soils consist of boulders and fragments of dolerite in a matrix of sand and clay. They have been developed on the dolerite mountains in the centre, east and south east of Tasmania. The soils seem confined to those mountains which rise above six hundred metres, although the soils themselves may extend below this critical height.

The soils occur on material which was produced during the Recent **periglaciation.** The soils are often stony and are found on steep slopes and grow little else but eucalypts.

Alluvial and related soils

These soils occupy flood plains or young river terraces, and occur along water courses in the drier, eastern half of Tasmania. The surface horizons are commonly acid at the top and alkaline below. The soils are used fairly extensively for a variety of agricultural and horticultural crops, but there is always the associated risk of flood damage.

Peats

Where the decomposition of plant and animal residues is sufficiently restricted, organic matter may accumulate at the surface of the soil to such an extent that peats are developed. Decomposition of organic matter may be restricted either by low temperatures or poor drainage or a combination of both. Low temperatures and poor drainage have contributed to the formation of peats on the Central Plateau where high moor peats are common.

Restricted drainage has been instrumental in the formation of the moor peats (button grass peats) to be found on the valley floors and plains of the South West.

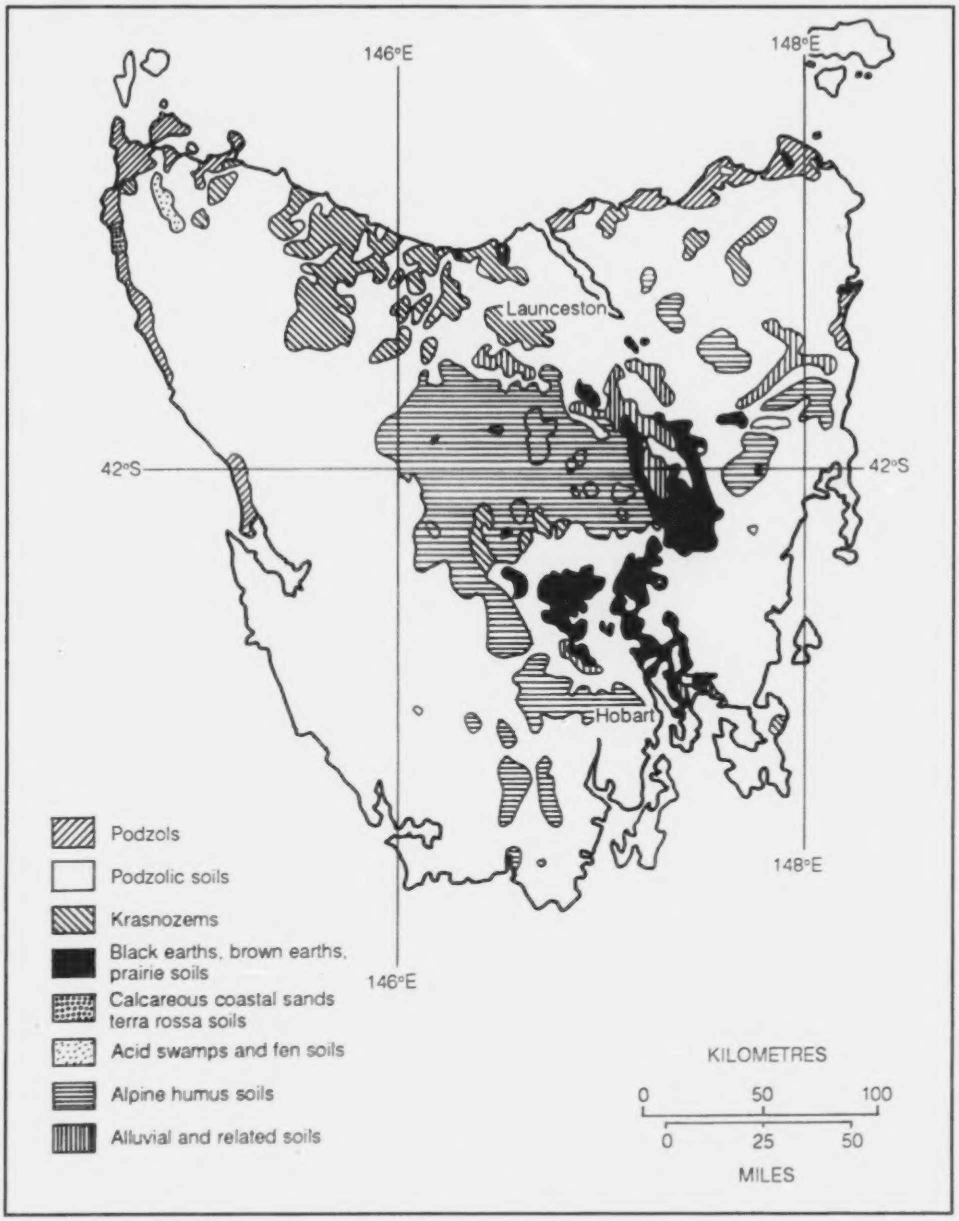

146°E
148°E
Launceston
42°S
42°S
Hobart
148°E
146°E
Podzols
Podzolic soils
Krasnozems
Black earths, brown earths, prairie soils
Calcareous coastal sands terra rossa soils
Acid swamps and fen soils
Alpine humus soils
Alluvial and related soils
KILOMETRES
0
50
100
0
25
50
MILES

Fig. 3.5: Soil map of Tasmania.

The fertility of Tasmanian soils

Like most Australian soils, Tasmanian soils are not very fertile by world standards. However, because of the adequate rainfall, the soils may become quite productive when fertilizers are added.

The **nitrogen** requirements of the soil are usually met by the growing of legumes. For certain crops and for dairying pastures, nitrogen fertilisers such as ammonium sulphate are added.

The continued use of superphosphates is overcoming the deficiency of **phosphorus.** This is of particular significance in areas of intensive farming.

Tasmanian soils seem to contain little useable **potassium**, and this deficiency may require greater attention as the intensity of farming is increased. It has already created a problem on sandy soils and on those podzolic soils which have been cropped for a long period of time.

Of the trace elements, the deficiency of **molybdenum** is most noticeable. This is especially so on some of the podzolic soils, and on the krasnozems. On the north coast and on King Island, the podzols and sandy soils are commonly deficient in **copper**. These soils, together with some of the krasnozems, also often require the addition of **cobalt**. Stock are prone to deficiency diseases in areas where pastures are grown on soils which are deficient in these elements.

The distribution of soils is illustrated by figure 3.5. This has been adapted from the work of K. Nicolls and S. Dimmock (published in the Atlas of Tasmania, 1965).

In Hobart there are three main groups of soils: young or immature soils such as alluvials; soils of moderate age derived from basalt or dolerite (bluestone); and podzolic soils which are old, highly leached and distinctly layered.

Soils in the urban areas of Launceston are highly variable because over a period of years large quantities of soil have been brought in from surrounding districts to establish and topdress local gardens.

The natural soils in Launceston can be divided into three main groups: young or immature soils such as alluvials (Quaternary deposits); soils derived from clays, gravels and sands (Tertiary deposits); and soils derived from dolerite (Jurassic). Within these groups there are a number of soil types.

Soil erosion

"Soil erosion is widespread and severe throughout the settled parts of Tasmania, and a continuous erosion hazard exists in many areas."

This is the picture given by J. Colclough, who for a number of years was Soil Conservation Officer with the Tasmanian Department of Agriculture. He was concerned with the types and causes of soil erosion and with the effects and control of this erosion.

The soil erosion problems existing in Tasmania have been caused by a lack of appreciation of the delicate **equilibrium** existing between four important factors:

- *climate*, mainly rainfall and temperature;
- *soil*, and its limited ability to resist erosion and absorb water;
- *topography*, especially the steepness and length of slopes;
- *plant cover*, which includes both living and dead vegetation.

All types of soil erosion are evident throughout the State — **sheet, rill, and gully erosion, tunnels, earthflows, stream bank erosion** and extensive **wind erosion** of sand dune and high plateau areas.

Active soil erosion of all types is still occurring in all settled areas. Soil erosion is particularly critical in places where there are extremely steep slopes and long slopes, erodible soil types and prolonged periods of rainfall.

Sheet erosion

Most of Tasmania's soil erosion is of an inconspicuous type called sheet erosion. This involves the washing away of a more or less even layer or sheet of soil. This type of erosion may not be readily discernible. It begins with the splash action of raindrops on unprotected soils and is continued by the film of run-off flowing over the land surface.

Sheet erosion is most severe on the Central Plateau and other high mountain areas, on the unimproved hillslopes of sheep-run country, and generally on all sloping arable and grazing lands which have been used beyond their capabilities. The use of fire, overgrazing, clearing for woodchips and engineering activities tend to make the problem worse.

The fact that sheet erosion is not readily visible is a problem. Very often centimetres of valuable soil may be removed without any outstanding surface marking. It is believed that it takes between 200 and 2,000 years to form just a few centimetres of topsoil, under the most favourable conditions. Soil is therefore virtually a non-renewable resource and soil erosion must be prevented.

However, sheet erosion can be observed. A close examination of water flowing over a bare area will reveal soil particles being carried away. Sheet erosion is also discerned by the presence of elevated tufts of grass which have their roots partially exposed. This results from sheets of soil being washed from round them. And the accumulation of silt on the uphill-side of stones and fallen tree branches is evidence that sheet erosion must be taking place further upslope.

Sheet erosion is all too common on farmland in the North-West, particularly after ploughing. It is initiated by raindrops which hit the exposed soil surface and act like so many little picks chipping away at the soil. As each drop strikes bare ground, it does so with a splash and hurls dislodged particles into the air. On a perfectly flat surface these particles would land more or less uniformly around the point of impact, but on a slope this is not the case. For example, on a 10° slope three quarters of the dislodged material lands on the downhill side. Over a period of time this can produce considerable thinning of surface soils, even without the presence of running water.

Raindrops are also responsible for packing soil particles together and breaking granules into finer particles. These fine particles may be carried into pore spaces where they are trapped and restrict water infiltration. The result is that both run-off and erosion are increased.

Fig. 3.6: This field shows an example of sheet erosion where a thin layer of soil is washed away by water moving over the entire surface. The problem here was caused by over-grazing.

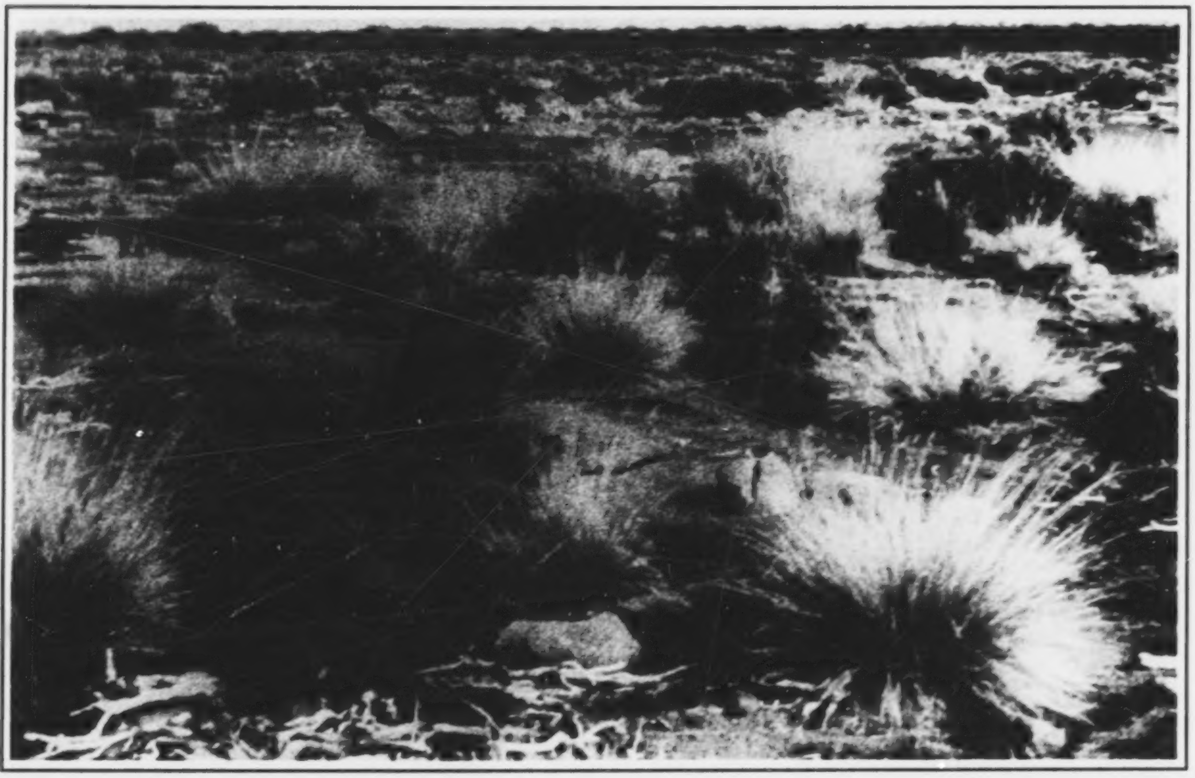


Fig. 3.7: Flowing water on sloping land eventually forms grooves in the surface. This is known as rill erosion.

Rill erosion

Usually closely associated with severe sheet erosion, it occurs where run-off concentrates in flowlines and cuts grooves or rills in the ground surface. It is most noticeable in areas where up-and-down hill cultivation are practised.

Gully erosion

A more obvious type of erosion is that which is known as gully erosion. It is a more advanced stage than rill erosion, occurring as a result of water concentrating in defined channels. Gully erosion can be seen in practically every settled portion of Tasmania. Gullies can be enlarged very quickly.

In a carefully documented example of gully erosion at Lower White Hills in 1947, the waterfall action of water running off from neglected pasture and arable land resulted in the head of the gully moving up hill 7.9 metres in two months. The gully had an average depth of 1.5 metres and an average width of 1.8 to 2.1 metres.

Gullies often begin in badly placed plough furrows, but they may also commence in stock trails and in the ruts left by the wheels of farm machinery and vehicles. Once this type of erosion starts, great gullies are gouged out and large areas of land may be ruined or made inaccessible. One of the effects of such gullies is that the water table may be lowered in the surrounding area, and this has a bad effect on crops.

Fig. 3.8: This photograph shows gully erosion. The small gutter leading to the dam is cut wider and deeper until the flow of water continues the gully head further up the hill.

Tunnel erosion

The incidence of tunnel erosion is far greater and its effects more widespread in Tasmania than was previously recognised. It is far more serious than in many other parts of the world.

Tunnel erosion occurs in soils which have a high salt (sodium) content in the subsoil. It occurs most frequently on podzolic soils formed on sandstones and mudstones, usually Permian or Triassic in age. One source of salt is from the moisture picked up from the sea. Another source of salt is from the weathering of the parent rock.

The percolation of dilute sodium-bearing water has resulted in the production of areas of highly dispersible clays. With excess water these can become fluid and flow downslope within the soil. This can result in serious gullying caused by the 'caving in' of the surface soil. The tunnel patterns then rapidly extend.

It is thought that one of the causes of tunnel erosion is excess water in the soil. This excess water is the result of changes in land use — the removal of natural vegetation and intensive cultivation often result in a raising of the water table. The crops that are grown tend to use less water than the former vegetation — so there is surplus water available which acts on the highly dispersible clays and causes them to become fluid.

Some promising progress in the prevention of tunnel erosion has been achieved by liming the soil. The calcium ions are able to replace sodium ions and thereby stabilize the soil.

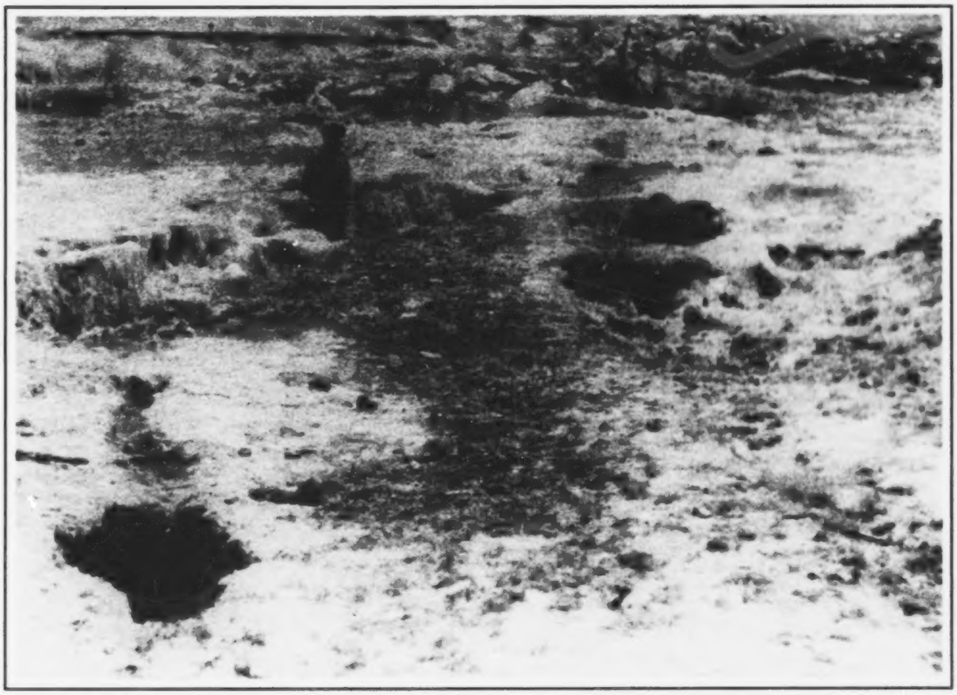


Fig. 3.9: Water flowing over the ground will soak in where there are small holes, old stumps or rabbit holes. Eventually the sub-soil washes out leaving underground tunnels. This is known as tunnel erosion.

Stream bank erosion

Another form of soil erosion is stream bank erosion. Stream bank erosion is the removal of soil from stream banks. This usually occurs during periods of high flow. In general, this type of erosion has 'graded' stream courses to such an extent that down-cutting occurs only in the upper reaches of the stream.

The removal of vegetation in the catchment areas by European settlers has meant that there is now rapid run-off whenever there are heavy downpours. Streams quickly flood. Rainwater is no longer absorbed to the same extent as it was before humans altered the pattern of vegetation. Where the water courses are partially or completely blocked by debris, the water is often diverted through river flats. These are particularly significant from the point of view of agriculture.

Wind erosion

This occurs on soils that are not adequately protected by vegetation. The most spectacular effects of wind can be seen in the drifting sand dunes around the coast.

Mass movement

This is the remaining form of soil erosion that is of interest in Tasmania. The mass movement of soil is indicated by earth slumping, landslides and earthflows. It is very noticeable on certain areas of cultivated krasnozem, especially after prolonged saturation by rain. Many slumps are the result of over-grazing, the destruction of vegetation on steep slopes, and excavations for building foundations, roads and railways.

Summary

Soil erosion results in the loss of soil and a decline in soil fertility, lower yields, and lower land values. Eroded land absorbs less rainwater. This results in increased run-off and flood hazard. Eroded material may also cause great damage by silting up water storages, destroying fences and covering roadways. Soil erosion therefore costs the community massive amounts of money. For all practical purposes soil is a non-renewable resource, a resource which Tasmania cannot afford to lose.

Soil conservation

To try to control and lessen the harmful effects of soil erosion it is necessary to apply soil conservation techniques to land-use management. *The major aim in soil conservation is to make any surplus water slow down, spread out and soak in.* There are various means by which this may be done, but perhaps the best way is to maintain a vegetation cover. Where this is not possible the following methods help to reduce water velocity and increase the rate at which water infiltrates into the soil:

- **Stubble mulching** is the term used when crop waste is ploughed back into the topsoil to help maintain the organic content and water-holding capacity of the soil.
- **Green manure crops** such as oats or tick beans may be grown for turning back into the soil. When turned back into the soil, green manure crops increase the soil's organic content and improve soil structure.
- **Strip cropping** involves strips of pasture alternating with cultivated crops, often parallel to the contours of the land or at right angles to the prevailing wind. The permanent strips of pasture slow down water on slopes and improve absorption.
- **Alternating a series of crops with a pasture phase** helps maintain soil structure.
- **Minimum tillage techniques.** Cultivation tends to destroy soil structure and so reduce infiltration by water. Therefore cultivation should be kept to a minimum. Where practicable, minimum tillage techniques should be used; for example, spraying with herbicides and drilling directly into crop residues or the undisturbed turf. The soil should never be cultivated when it is too wet, and the right implement should always be selected for the job. Some machinery is far harder on soils than others.
- **Contour farming** means ploughing, cultivating, sowing and harvesting the crops along the contours of the land.
- **Irrigation rates** must not exceed the absorptive capacity of the soil, or runoff and erosion will occur.

Many of the problems created by soil erosion could be prevented or lessened if a greater emphasis was placed on the value of soil. It must be impressed upon people that it is virtually impossible to replace the soil once it has been lost, that we only have a finite amount of soil, that we depend on soil for most of our food, clothing materials and many building materials and that our soils are being eroded.

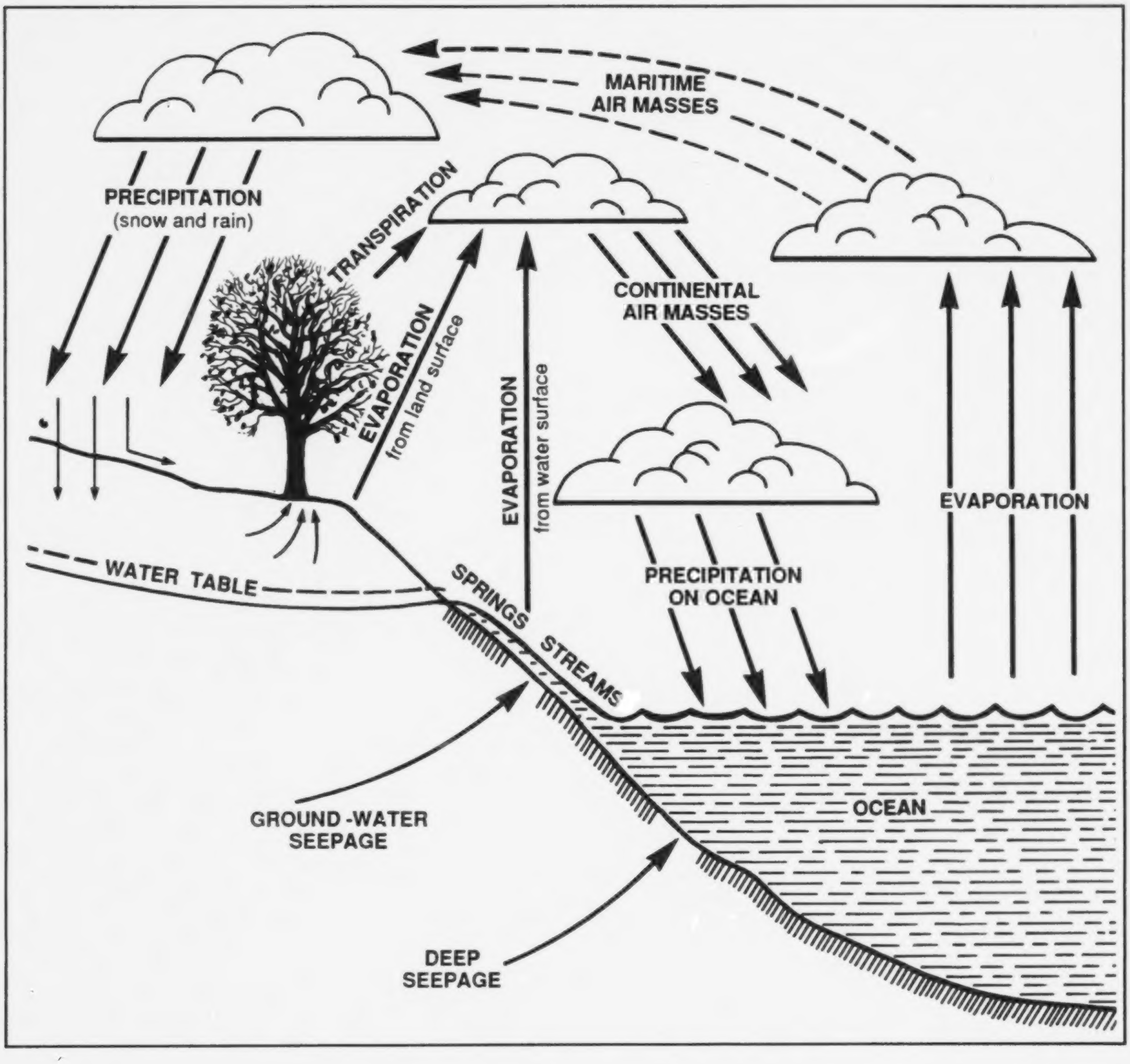
Groundwater

Andrew Scanlon

Introduction

The Earth's gravity, and energy from the Sun, are responsible for the continuous cycling of water from ocean to atmosphere, and from the land back to the ocean. Groundwater is one part of this dynamic system known as the **water cycle**. A large percentage of the precipitation that falls onto the land surface soaks into the ground and collects in the spaces in rock and sediment. From here it slowly moves into streams or back into the ocean.

Fig. 4.1: The water cycle.


MARITIME AIR MASSES
PRECIPITATION (snow and rain)
TRANSPIRATION
EVAPORATION from land surface
EVAPORATION from water surface
CONTINENTAL AIR MASSES
EVAPORATION
PRECIPITATION ON OCEAN
WATER TABLE
SPRINGS
STREAMS
OCEAN
GROUND-WATER SEEPAGE
DEEP SEEPAGE

Nearly all groundwater infiltrates at the surface as a direct or indirect result of precipitation **(meteoric water)**. Water derived from magma **(juvenile water)** and water trapped in rocks at the time of deposition **(connate water)** are academic curiosities and contribute insignificant amounts to the groundwater resource.

Figure 4.2 shows the divisions and some of the terminology associated with sub-surface water or ground water. Water absorbed at the surface can be held in the soil (trapped between fine-grained particles) but most flows down through the **zone of aeration** to the **water table**. Below this level, in the **saturated or phreatic zone**, the spaces are completely filled with water. Capillary action produces a fringe of water at the base of the **unsaturated** or **vadose zone**.

Most groundwater, including nearly all that is useable by man, occurs within 750 metres of the Earth's surface. Deeper down the water becomes slightly salty. At even greater depths (Fig. 4.3) increasing pressure closes rock spaces and the small amount of groundwater has a high salt content. Very little water, if any, occurs at depths greater than 10 kilometres.

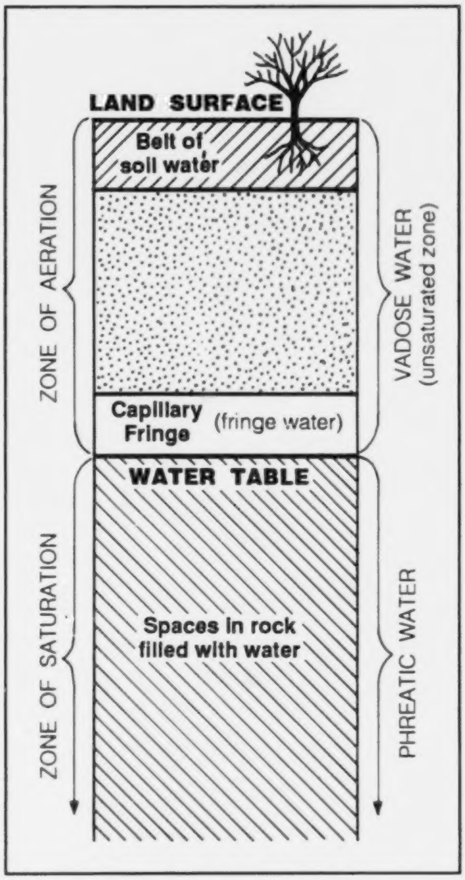

LAND SURFACE
Belt of soil water
ZONE OF AERATION
VADOSE WATER (unsaturated zone)
Capillary Fringe
(fringe water)
WATER TABLE
ZONE OF SATURATION
Spaces in rock filled with water
PHREATIC WATER

Fig. 4.2: Divisions of sub-surface water.

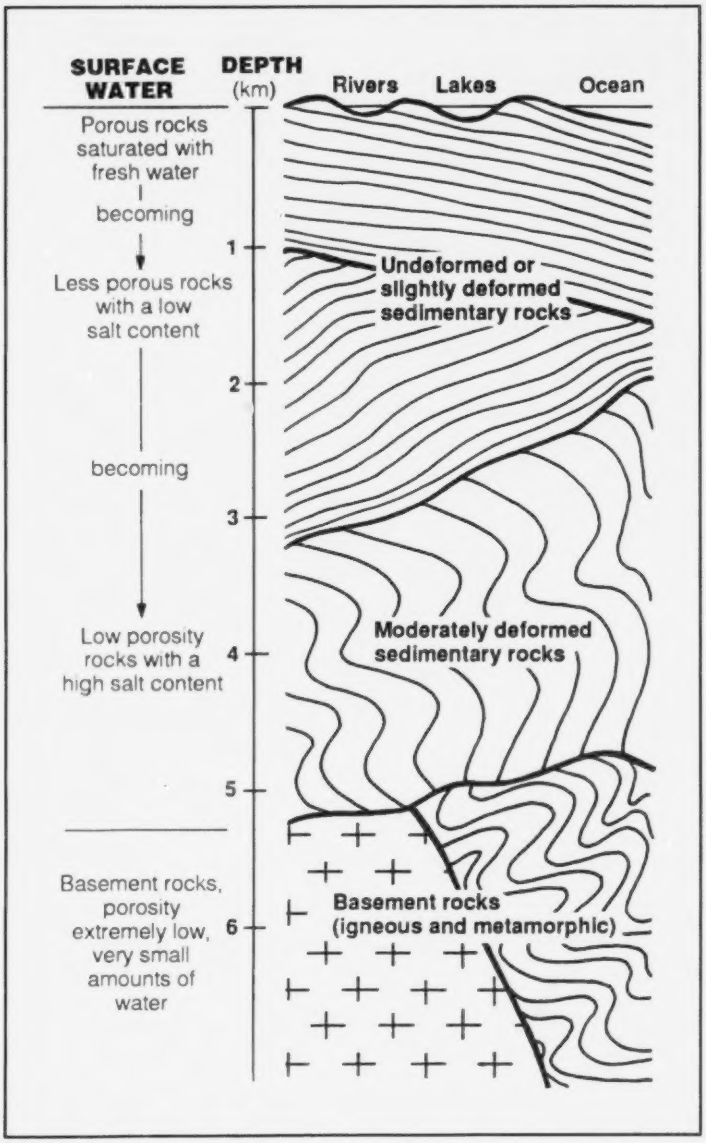

SURFACE WATER
DEPTH (km)
Rivers
Lakes
Ocean
Porous rocks saturated with fresh water
becoming
Less porous rocks with a low salt content
becoming
Low porosity rocks with a high salt content
Basement rocks, porosity extremely low, very small amounts of water
1
2
3
4
5
6
Undeformed or slightly deformed sedimentary rocks
Moderately deformed sedimentary rocks
Basement rocks (igneous and metamorphic)

Fig. 4.3: Changes in groundwater at depth.

Porosity

Groundwater resides mainly in the pore spaces of sediments and sedimentary rocks or in rock fractures. Underground streams are restricted to areas of soluble rock such as limestone, and make up only a very small percentage of total sub-surface water. The space in rock or sediment is termed **porosity** and is expressed as a percentage of total volume. Porosity is about 35% for unconsolidated sediments and rises to 50% for some silts and clays. Porosity decreases with increasing compaction and cementation, and most sedimentary rocks have porosities less than 20%.

Limestone porosity can vary from 1% to 50%, reflecting the variety of limestone types. Solution cavities in limestone increase its porosity.

Porosity of other rocks depends largely on the amount of fracturing and jointing. Some volcanic rocks contain vesicles which can hold water.

Percolation

The flow, or **percolation**, of groundwater in the phreatic zone depends on two major factors:

- **Permeability**
  Permeability is the property by which solids allow fluids to pass through them. It relates to the amount of space in the rock or sediment (porosity) and the degree of inter-connection of the spaces.

  Permeability is high in all unconsolidated sediments and sedimentary rocks, but is low in fine-grained sedimentary material such as clay, silt and shale. Permeability is low in such materials as fine-grained clay because the molecules of water are attracted to the fine individual grains across the small pore spaces in the clay — and the water is trapped.

  The permeability of igneous and metamorphic rocks relates directly to the amount and degree of interconnection of joints and fractures.

- **Slope of the water table**
  The slope of the water table is the second factor affecting the percolation of groundwater. The water table occurs nearly everywhere at varying depths beneath the surface. Its distance from the surface is directly related to the amount of water **(or recharge)** flowing down through the vadose zone.

  The water table follows the topography, but in subdued form. Groundwater flows from high areas to low areas, and the steeper the slope of the water table, the more rapid the flow. In times of low recharge (a dry spell) the water table lowers and flattens out. Where the water table intersects the land surface springs and permanent water bodies such as lakes and streams occur.

The rate at which groundwater percolates varies from 15 centimetres per day to close to zero. A few centimetres per day is average for most permeable bodies or **aquifers.**

Confined aquifers are found between two impermeable bodies or **aquicludes.** Figure 4.4 shows confined and unconfined groundwater flow. Recharge of confined aquifers occurs at some distant locality where the permeable strata intersect the surface.

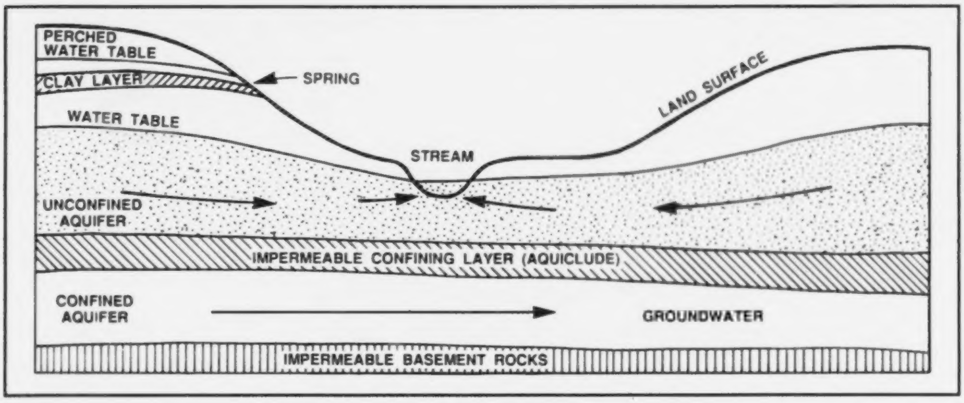
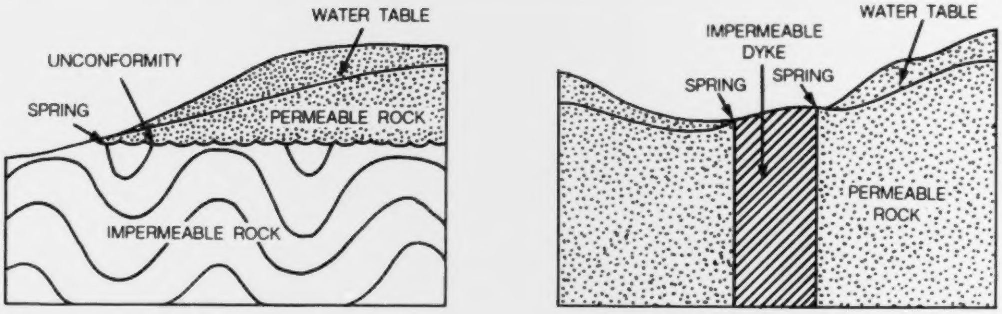


Fig. 4.4: Diagram showing occurrence of groundwater.

Springs

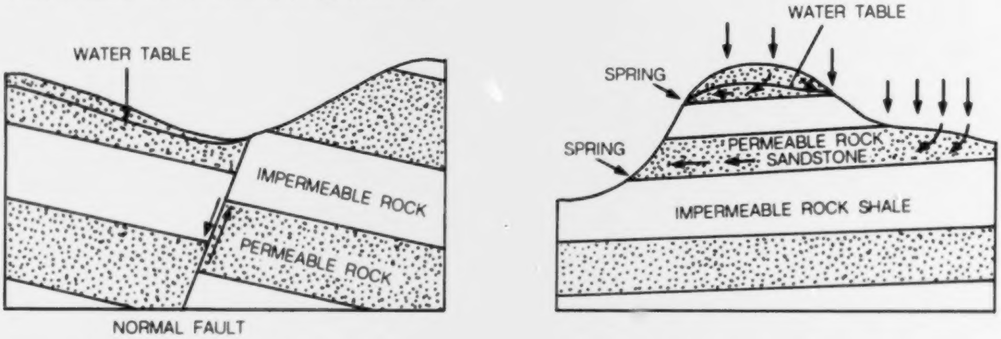
Artesian conditions are found where springs or wells intersect confined aquifers which have heads of pressure sufficient to force water out onto the surface. Figure 4.5 shows the importance of aquicludes in the location of springs.

Springs can also occur where there are changes of slope in the land's surface, where closely-spaced and inter-connecting joints or fractures intersect the surface, and where there is cavernous rock such as limestone.


WATER TABLE
UNCONFORMITY
SPRING
PERMEABLE ROCK
IMPERMEABLE ROCK
IMPERMEABLE DYKE
WATER TABLE
SPRING
SPRING
PERMEABLE ROCK

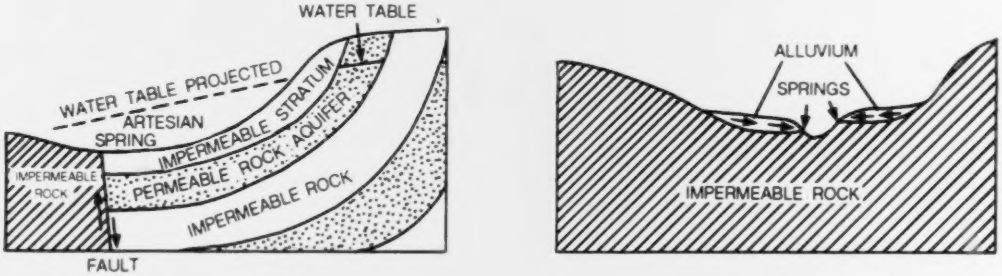
Spring at an unconformity. The underlying basement rock may be a tilted or folded impermeable rock or a massive igneous rock.

Spring at junction of impermeable dyke and permeable sediments.


WATER TABLE
IMPERMEABLE ROCK
PERMEABLE ROCK
NORMAL FAULT
WATER TABLE
SPRING
SPRING
PERMEABLE ROCK
SANDSTONE
IMPERMEABLE ROCK SHALE

Spring at faulted junction between permeable and impermeable strata.

Springs at the junction of dipping permeable and underlying impermeable sediments.

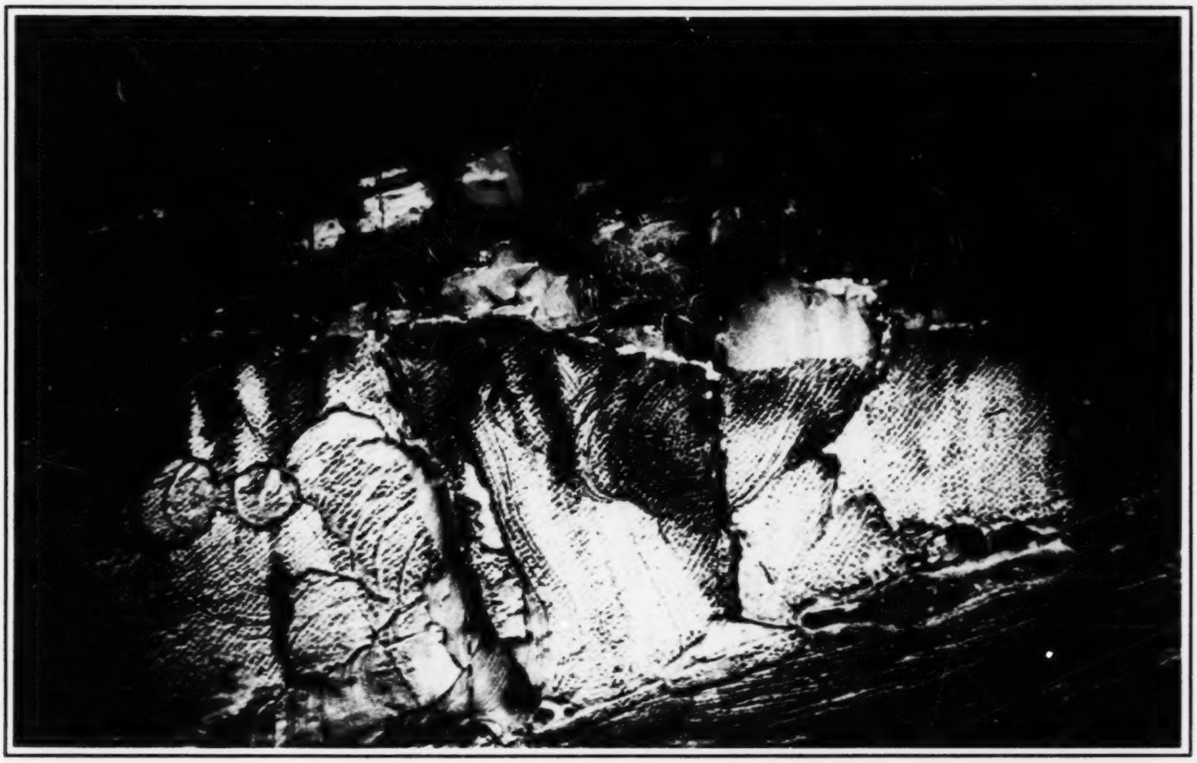

WATER TABLE
WATER TABLE PROJECTED
ARTESIAN SPRING
IMPERMEABLE STRATUM
PERMEABLE ROCK AQUIFER
IMPERMEABLE ROCK
IMPERMEABLE ROCK
FAULT
ALLUVIUM
SPRINGS
IMPERMEABLE ROCK

The artesian basin is faulted against impermeable rock. The water under pressure in the aquifer is released along the fault as an artesian spring.

Springs at the junction of alluvium and underlying impermeable rocks.

Fig. 4.5: The importance of aquicludes in the location of springs.

Fig. 4.6: *The effect of movement of iron-rich groundwater through permeable Triassic sandstone at Midway Point.*



Groundwater and the rock cycle

Groundwater is an important factor in the formation of many rocks and minerals. Sedimentary rocks are formed by the compaction and cementation of loose sediments. Groundwater contains dissolved material which can be chemically precipitated around grains of sediment. The type and amount of this cement has a marked effect on the properties of the sedimentary rock. Later movement of groundwater through permeable material can dissolve and redistribute cement.

Figure 4.6 shows patterns in Triassic sandstone produced by the movement of iron-rich groundwater. Figure 4.7 shows the resistance to weathering created by the concentration of cement around joints in sedimentary rock. The ability of groundwater to dissolve and deposit material is very obvious in limestone areas.

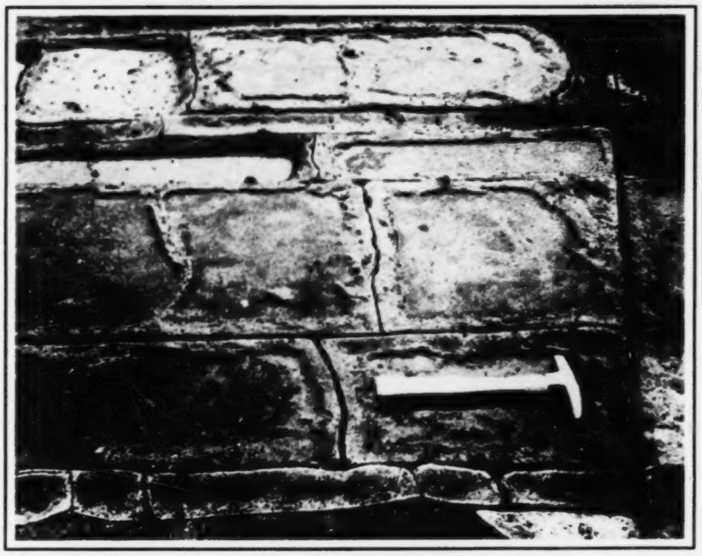


Fig. 4.7: *The tessellated pavement at Eaglehawk Neck shows the raised rims of well cemented material along the joints.*

Spring deposits

Groundwater often deposits materials around springs. Where a cone of material builds up the term **mound spring** is used (see Figure. 4.8). Alternations of black peat and calcareous matter appear to be typical of the Mowbray Swamp mound springs near Smithton.

Springs are often associated with deposits of silica and travertine (calcium carbonate). Figure 4.9 shows calcareous deposits accumulating at the foot of a spring south of Blackmans Bay. There is a Tertiary spring deposit at Geilston Bay which in the early history of Hobart yielded quite a lot of lime. Charles Darwin visited the deposit and collected some fossil leaves and gastropods when he came to Tasmania in H.M.S. *Beagle* in 1832. At present there is little to be seen apart from a few isolated blocks of brown siliceous material and traces of white to yellowish-brown travertine.

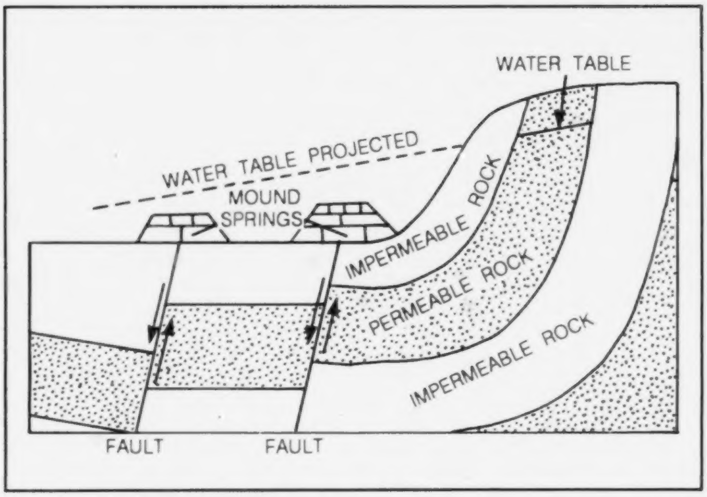


Fig. 4.8: An artesian basin with mound springs. The springs contain dissolved mineral salts deposited at the surface as a mound.

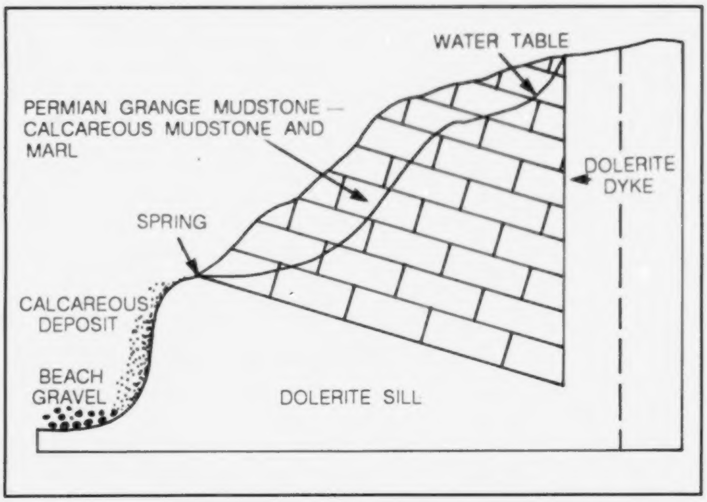


Fig. 4.9: A spring, south of Blackmans Bay in Southern Tasmania.

It is common to find deposits of halite and gypsum near seepages from Tasmanian Triassic sandstones. They are most frequently found in the caves that occur in exposed cliffs.

Fossil or petrified wood

The organic remains of plants and animals are often replaced by mineral matter dissolved in groundwater. Petrified wood can be found in many localities. The original structure and pattern of the cells may be perfectly retained though no trace of wood itself remains.

Tasmania's best known occurrence of fossil wood is at Macquarie Plains in the Derwent Valley. The fossil wood is found in a sequence of basalt lava flows and volcanic ash. The opalised trees form part of a fossil forest. Some of the trees recovered measured up to half a metre in diameter; and the tallest portion of a tree was reported to be six metres high.

Several fossil trees, in the prone position, were uncovered when the Brooker Highway was built through Hobart's northern suburbs. The enclosing rocks were post-basaltic sands and gravels.

Fragments of petrified wood are often associated with Tertiary gravels. Calcareous shells in sedimentary rock can often be silicified by the action of groundwater. Silica has replaced shells, algal material and possibly evaporites at different levels in Tasmania's Ordovician limestone.

Hot springs

Where groundwater is heated, it becomes a much more efficient solvent of minerals and carries a lot of material in solution. Hot mineral-rich waters are found in areas of igneous activity or high heat flow where groundwater has moved deep below the surface and been heated. Figure 4.10 shows the possible origins of the thermal spring, near Hastings Caves. Another hot spring exists at Kimberley on the North-West coast.

Hot springs are often associated with large deposits of silica and travertine. Sulfide deposits are also common. Where large amounts of sulfur are dissolved in the hot water it is likely that juvenile (or magmatic) water has been mixed with the water of meteoric origin. In countries such as Iceland, Italy and New Zealand the geothermal energy associated with hot springs and geysers has been harnessed to produce electricity.

Ore deposits and groundwater

Ore deposits are aggregates of minerals from which one or more materials can be extracted profitably. Ores usually result from the concentration of minerals. There are many ways this concentration may take place, but groundwater often plays an important part.

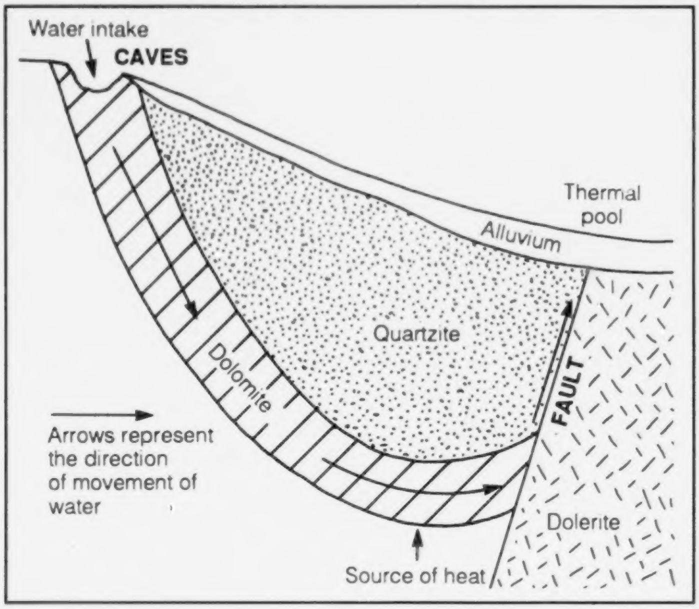
Groundwater, possibly heated by nearby igneous bodies, and containing dissolved materials from magmatic and/or weathering sources moves through permeable material dissolving small amounts of such minerals as galena, chalcopyrite and sphalerite.

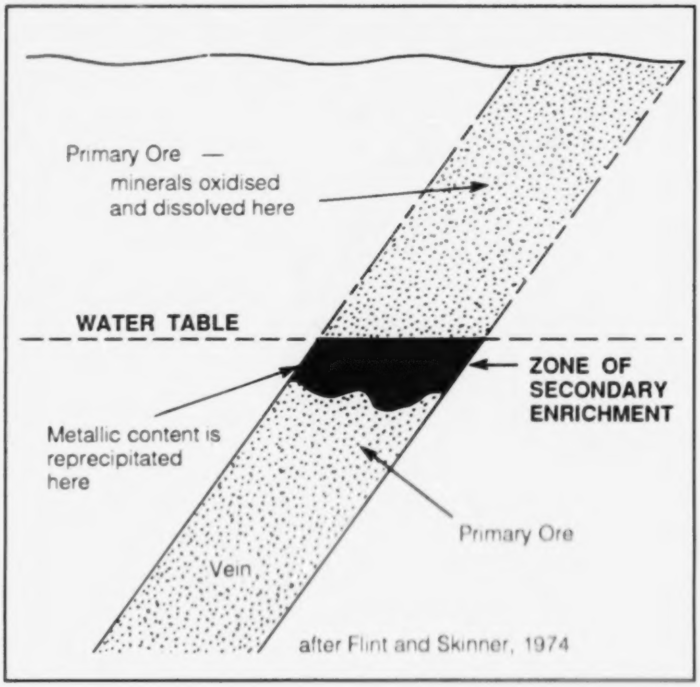
Where these solutions find an open fracture or a body of shattered rock, deposition may occur. The massive sulfide deposits in western Tasmania are thought to have originated from the circulation of hot water through permeable volcanic material.

Groundwater also produces mineral concentrations by two other processes:

- The first is **secondary enrichment** (Fig. 4.11) where downward movement of groundwater naturally enriches a primary ore body.
- The second method is **residual concentration** where a mineral substance is concentrated by the removal of a different substance with which it was associated. Bauxite deposits near Launceston were formed by this process — the downward movement of groundwater has removed the silica in preference to aluminium oxides (bauxite).

Fig. 4.10: An explanation of the thermal springs, near Hastings Caves.


Water intake
CAVES
Thermal pool
Alluvium
Quartzite
Dolomite
FAULT
Arrows represent the direction of movement of water
Dolerite
Source of heat


Primary Ore — minerals oxidised and dissolved here
WATER TABLE
ZONE OF SECONDARY ENRICHMENT
Metallic content is reprecipitated here
Primary Ore
Vein

after Flint and Skinner, 1974

Fig. 4.11: Descending groundwater dissolves ore above water table and produces secondary enrichment below.

Chapter four

The groundwater resource in Tasmania

Introduction

Groundwater is an important resource in areas where surface run-off does not provide an adequate year-round supply for agricultural, industrial or domestic purposes.

In Tasmania's west, rainfall exceeds evaporation so that surface water is widespread. A number of mining ventures in western Tasmania met with failure because the large quantities of groundwater that entered the workings could not be handled by available pumps.

Fig. 4.12: Tasmania's annual rainfall and evaporation.

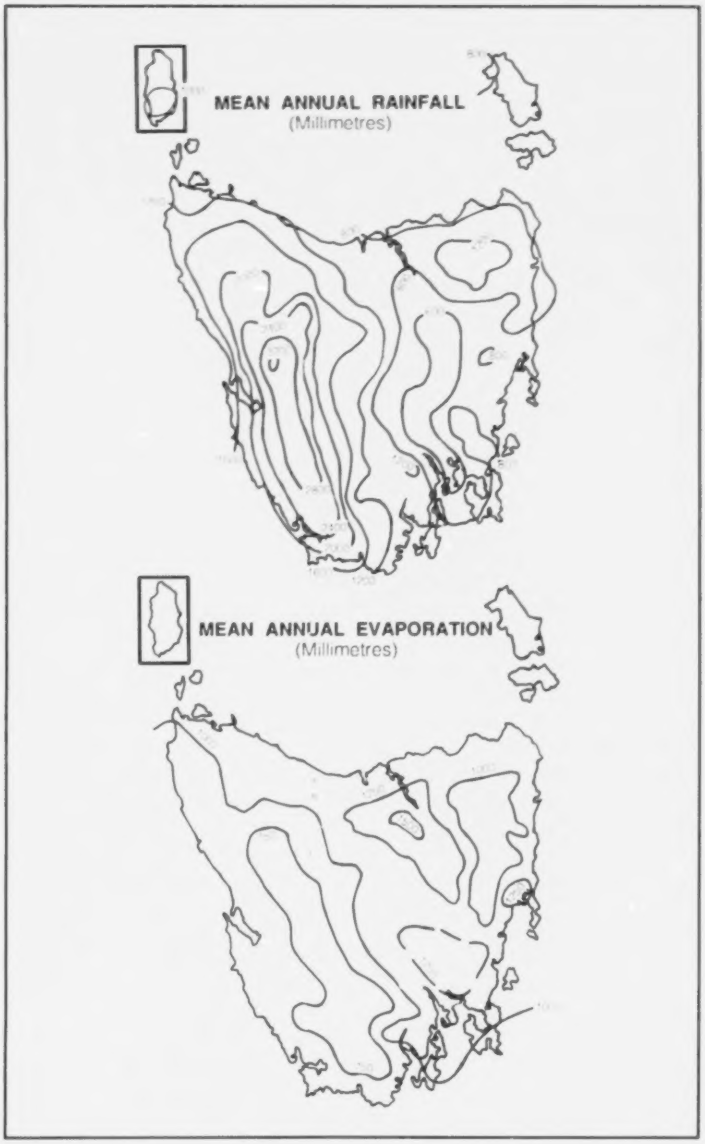


Figure 4.12 shows mean annual rainfall and evaporation across Tasmania. **Effective rainfall** is the amount of rainfall necessary to compensate for evaporation, begin germination and maintain plant growth above wilting point. In the Midlands, the Derwent Valley, the South East and the East, and in the northern inland, the chance of receiving effective rainfall during the summer months is very small.

Major cities and most towns have river-based water supplies of more or less good quality. Only Currie on King Island uses groundwater as its principal source of water. Nevertheless, for more isolated villages and farms, **water bores** are important. A water bore is a source that is available locally in what may otherwise be a dry location. They are usually reliable in all seasons, cheap after the first capital expense, and pollution-free when reasonable care is taken.

Prospecting for groundwater

Groundwater is in many ways an unknown resource. The first problem is that people are often reluctant to invest money in prospecting for something that falls out of the sky at no cost. The next drawback is that during some months of the year there hardly seems to be a shortage of water. The third and probably most important problem is that groundwater is hidden away below the ground surface. Even with modern methods of geophysical prospecting, it isn't easy to find good groundwater supplies. Success depends on a knowledge of the long-term rainfall, the topography, and the permeability of the rocks in which the search is conducted.

Even though a belief in **water divining** still persists in some quarters, it has no recognised scientific basis and therefore must be compared with divination of the future by the flight of birds or the examination of goat entrails. Controlled scientific investigations provide no evidence that water has any property that will influence a bent wire or a forked twig. Diviners are 'successful' in areas where groundwater is well nigh universal.

When prospecting for groundwater, the geology, topography and climate need to be carefully considered. The yield of future bores will depend on such things as:

- *the rock type;*
- *the amount of fracturing and weathering;*
- *the presence of faults and dykes; and*
- *the nature of the catchment and rainfall.*

In the initial stages of an investigation the surface geology is studied and any springs and seepages located. Geophysical surveys are carried out to gain a clearer picture of the underlying geology. In the final stages of the investigations bores are drilled and various geophysical and pump tests carried out.

There is still much potential for the development of the groundwater resource in Tasmania. Leaman estimated in 1971 that only 0.3% of the annual recharge was being utilized in the most developed area of the Coal River Basin (Tunnack).

Water quality

The quality of a body of water refers to its temperature and the amount and character of its mineral particles and organic matter (chiefly bacteria) in relation to its intended use. The most common source of pollution is **sewage.** Drainage from septic tanks, broken sewers and stock-yards contaminates groundwater. The infection most commonly communicated by polluted water is typhoid.

If water contaminated with sewage bacteria passes through material with large openings, such as very coarse gravel or cavernous limestone, it may travel long distances without much change. If, on the other hand, it percolates through sand or permeable sandstone, it becomes purified within a short distance (sometimes within as little as 30 metres).

Principal materials dissolved in natural waters

The principal materials dissolved in natural waters are calcium, magnesium, sodium, chloride, sulfate and bicarbonate. Silica, iron, aluminium, potassium, fluoride, nitrate and borate are naturally present in small amounts. The amount and type of chemical constituents present depend upon the past history of the water. Contamination via magmatic sources (juvenile water) leads to high sulfate concentrations. High total salt content results from mixture with connate or present-day sea water.

Most dissolved material in groundwater comes from contact with surrounding rock. The more surface area exposed, and the longer the duration of contact, the more mineralized the water becomes. In general, the steeper the gradient of the water table, the shorter the duration of contact.

Hardness

The hardness of groundwater is a characteristic commonly noted by the large amount of soap required to form a lather. The carbonates and bicarbonates of calcium and magnesium produce 'temporary hardness'. **Temporary hardness** may be removed by boiling.

'Permanent hardness' is caused by the sulfates and chlorides or calcium and magnesium.

Temporary hardness is more common and causes deposits in pipes and various cooking utensils. Domestic and industrial uses are limited if magnesium sulfate is present in any quantity. Sulfate ions may be derived from sulfides and fertilizers; they impart a bitter taste to the water.

Iron is often present in Tasmanian groundwater, especially where dolerite is in abundance. Where iron content is large, growth of iron bacteria sometimes results in the blockage of pipes.

Large quantities of sodium in groundwater cause soil problems if the water is used for irrigation.

In order to prevent corrosion of metal ware, the pH(acidity) of groundwater should be between 5.5 and 8.6 .

In Tasmania there are only a few instances of groundwater quality deteriorating over time. When deterioration has occurred, it has been caused by organic matter entering the well or bore, or silting has taken place. Indeed, cases are known where the quality of groundwater has improved with time. For example, the town supply from coastal sands at Currie on King Island improved when the **total dissolved solids (TDS)** content of the water decreased from 761 mg/l in 1952 to 580 mg/l in 1980. The water supply has been from the same area over this period.

Groundwater in South-East Tasmania

The rocks and unconsolidated material of this area range in age from Late Carboniferous to Recent. The near horizontal sedimentary rocks of the Parmeener Super-Group (Late Carboniferous - Triassic) consist mainly of mudstones and sandstones. Surprisingly the late Permian mudstones are the best aquifers. All water is contained in fractures on bedding planes. Bore yields normally range from about 1000 - 2000 litre/hour with 4500 lph recorded at Tunnack.

Water in Triassic sandstones may be contained in primary pore spaces or in secondary openings such as bedding, partings, joints, fractures and areas of cement removal. Bore yields are variable. Where feldspar has weathered to clay the rocks are not suitable for aquifers.

Jurassic dolerite in a weathered and fractured state is sometimes highly porous and permeable. A survey of the records of over 100 Tasmanian bores that have penetrated greater than 6 metres into dolerite suggests a success rate greater than 50%. But dolerite is often in unfavourable topographic locations, difficult to drill and yields generally low flow rates of groundwater.

Fault zones transmit large quantities of water where the surrounding rocks are heavily fractured. Where weathering has produced large amounts of clay these fault zones can be effectively sealed.

The best aquifers are in unconsolidated Tertiary and Quaternary sediments. Lack of cementing material means that these rock types are highly porous and permeable.

Basalt aquifers in the Devonport area

The vesicular basalt in the Devonport area is one of the most productive of aquifers because it stores large amounts of water and transmits it readily. Yields are lower if the rock is weathered (because clay weathering products seal openings) or the vesicles not interconnected.

The area of Devonport centred on the towns of Moriarty and Wesley Vale is one of Tasmania's most productive farming areas. It also has the highest bore density in Tasmania, with over 250 bores extracting water from the underlying Tertiary basalts and sands.

A thick succession of sand, clay and basalt was deposited in deep fault-controlled basins (bounded by Jurassic dolerite) which developed in early Tertiary times. (Fig. 4.13) Two major volcanic episodes produced the Thirlstane Basalt and Moriarty Basalt, separated by a phase of weathering and deposition (the Wesley Vale Sand). All three units overlie a thick sequence of lake sediments (the Harford Beds).

Only the basalts produce reliable bores. In terms of volume, the Thirlstane Basalt is the larger of the two. It extends throughout the district and is lenticular in shape. Buried beneath the Wesley Vale Sand, the Thirlstane Basalt has escaped deep weathering and is up to 160 metres thick in places. Consisting of many superimposed thin lava flows, its porous nature makes it a relatively productive and very reliable aquifer by Tasmanian standards. Typical yields from bores are 12000 - 24000 l/h, with an average salinity of 350 mg/l TDS. Yield often increases

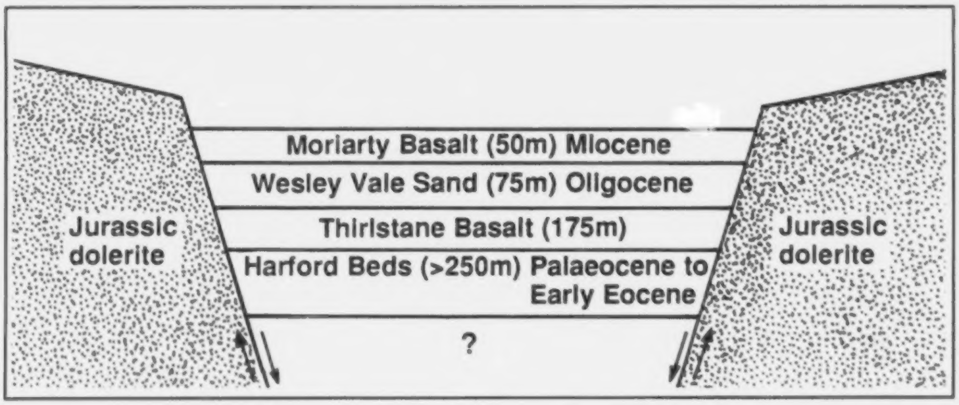

Moriarty Basalt (50m) Miocene
Wesley Vale Sand (75m) Oligocene
Jurassic dolerite
Thirlstane Basalt (175m)
Jurassic dolerite
Harford Beds (>250m) Palaeocene to Early Eocene
?

Fig. 4.13: Simplified geological sketch showing the stratigraphy and basalt aquifers in the Devonport area.

with depth drilled, as more water-bearing porous zones are intercepted. Some deeper bores yield proven rates of 48000 l/h. Reported untested yields are sometimes as high as 96000 l/h. In all cases the water is confined groundwater.

All that remains of the younger Moriarty Basalt are isolated cappings on higher land near Sassafras and Northdown. The basalt is up to 60-70 metres thick and is usually completely or very deeply weathered to brightly coloured textured clay. Bore yields are low, and there are many complete failures because the basalt's natural porosity and permeability has been reduced by weathering. Average yields of successful bores range up to 12000 l/h, but most are lower than this. Groundwater salinities average 150 mg/l TDS.

Groundwater in Launceston and North-East Tasmania

The oldest rocks in the Launceston area are the Silurian-Devonian Mathinna Beds. Their highly fractured and folded sediments are very reliable rock-fracture type aquifers. Granites, which intrude these Mathinna Beds, are poor aquifers. Parmeener Super-Group sediments are also generally poor aquifers, although high yields have been obtained where bores have reached the underlying Mathinna Beds.

Basalts are the most important porous-rock aquifers in N.E. Tasmania. The yields vary for each basalt locality. The Scottsdale basalts are poor yielding because they are so very deeply weathered, and only exceptional bores give yields above 4400 l/h. In the upper Ringarooma Valley the basalts possess little vesicularity and the bore yields are very low.

The yields around Winnaleah are more attractive, between 4400 - 13200 l/h. The existing town supply of Winnaleah is from basalt, with a sedimentary sand lens acting as a collector in these basalts.

Unconsolidated sediments provide the largest amount of groundwater used in North and North East Tasmania. In the Launceston Tertiary Basin groundwater occurs in sand, fine gravel, conglomerate and in boulder beds that are interbedded with finer sediments. Some of the fine-sand aquifers have been pump tested at up to 40,000 litres per hour.

Of the aquifer types in North East Tasmania, unconsolidated sediments provide the largest amount of groundwater used in the area and constitute the greatest potential reserve. The highest-producing bores are the sands, grits and gravels mixed with clay of Tertiary age. These granite-derived sediments, which are known in the area as the 'tin sediments', occur in small sedimentary basins as at Mount Cameron or in the Scottsdale basin between North Scottsdale and the coast. Similar basins hidden beneath basalt lavas occur at Rushy Lagoon, Gladstone and Cape Portland.

Valley fill basalts overlie these sediments between Ringarooma and Winnaleah.They also cap hills in the Pipers River region. In all these geological situations the Tertiary gravels and sands give high-yielding bores with excellent quality groundwater. Bore yields vary with the thickness of sediment and the percentage of clay present. Yields in excess of 4400 litres/hour are not uncommon.

Groundwater in coastal sands

Along the Tasmanian coast, almost all the landforms that have been formed as the result of deposits made by the sea or the wind contain useable groundwater. These deposits of sand are unconsolidated, and were formed during the Holocene Epoch (the last 10,000 years) when the sea level rose to its present position. The deposits of sand include **dune systems** behind beaches, **tie barriers** (for example, the neck joining north and south Maria, and the neck that joins north and south Bruny Island) and **bayhead barriers** (for example, Seven Mile Beach, and Nine Mile Beach at Swansea).

Behind beaches, pockets of groundwater may occur in the sands overlying the local bedrock. In tie barriers, the groundwater body is bounded on both sides by salt water. In most bayhead barriers the landward end of the spit is usually backed by low-lying swamps underlain by lagoonal and estuarine sediments containing poor quality groundwater.

The groundwater in coastal sands is usually unconfined. Water tables are shallow (generally less than three metres below the surface), sloping seawards from a metre or so above sea level to intersect the coast between high and low water marks.

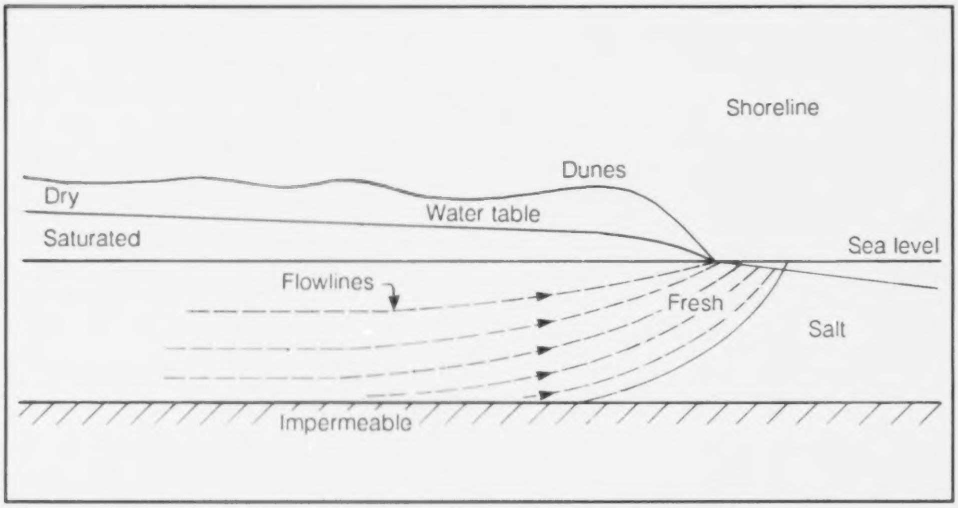


Fig. 4.14: Groundwater flow pattern near the coast for a typical unconfined aquifer underlain at shallow depth by impermeable material.

The aquifers in tie barriers and bayhead barriers often extend to about 10 metres below sea level where the water-bearing sand rests on impermeable clay or bedrock. The systems are recharged by infiltrating rain and ponded surface run-off, and each discharges naturally to the coast at sea level.

All coastal groundwater systems are therefore dynamic systems, exhibiting a continuous slow percolation of groundwater from recharge to discharge areas. This coastwards-migration of fresh, less dense water prevents the more dense seawater from invading the aquifer. All coastal aquifers therefore exhibit a freshwater-salt water interface — a thin zone of brackish water dipping steeply landwards from high water mark (Fig. 4.14).

Coastal aquifers in high rainfall areas contain fresher groundwater than low rainfall areas because they are more effectively recharged.

Artesian water in Tasmania

Artesian water is not common in Tasmania, although isolated bores in a number of areas have produced small flows. There are three areas where groups of bores have produced artesian water:

- The first region is in the lower-lying areas of the Launceston Tertiary Basin (Cressy-Longford area) where the aquifers are fine sand.
- The second is in the Spreyton area where the aquifer is coarse gravel/conglomerate at the base of the Permian sequence. Flows of up to 6400 l/h have been obtained in the former area and about double this amount in the latter.
- The third area is in the Midlands where artesian aquifers are confined by layers of shale in Triassic rocks.

Flow-rates in excess of 6000 l/h have been obtained at all three localities.

Karst

Introduction

Karst is defined as terrain with distinctive characteristics of relief and drainage that arise primarily from the fact that the rock is ***highly soluble*** *in natural waters, relative to other rocks.* The word 'karst' is often used as an adjective to refer to rock, water, streams, caves and other features making up such a landscape.

Three main rock groupings, **limestone, dolomite** and **evaporites**, are subject to a high degree of solution weathering and develop karst features. Limestone, consisting mainly of calcite ($CaCO_3$), is by far the most important. Dolomite $[CaMg(CO_3)_2]$ and evaporites (halite, anhydrite and gypsum) are less abundant. All rocks are soluble to some extent and even granite can develop minor solution features.

Figure 4.15 shows the distribution of karst areas in Tasmania. Caves have developed in Precambrian dolomite at Hastings in South-

East Tasmania. Less extensive caves and some surface karst occur in the same rock type in North-West Tasmania, the Mount Anne - Weld River area, Mount Ronald Cross, and near Tim Shea in the Florentine Valley.

The most important karst rock in Tasmania is limestone of Ordovician age. The most significant areas are Mole Creek and Gunn's Plains in northern Tasmania, the Franklin and Lower Gordon rivers and the Junee - Florentine area in the South-West and Central regions, and Ida Bay, Cracroft and Precipitous Bluff in the South-East.

Of less importance are the impure Permian limestones and minor occurrences of Tertiary limestone and wind-deposited Pleistocene limestone (aeolianite).

Rates of solution and cave formation

The solution and deposition of carbonate materials can be described by the following equation:

$$CaCO_{3\,(solid)} + H_20 + CO_{2\,(dissolved)} \rightarrow Ca^{2+} + 2HCO_3^{-}\ \text{(both in solution)}$$

Calcite is dissolved by the action of water made acidic by CO_2. The calcite is removed in solution as calcium and bicarbonate ions.

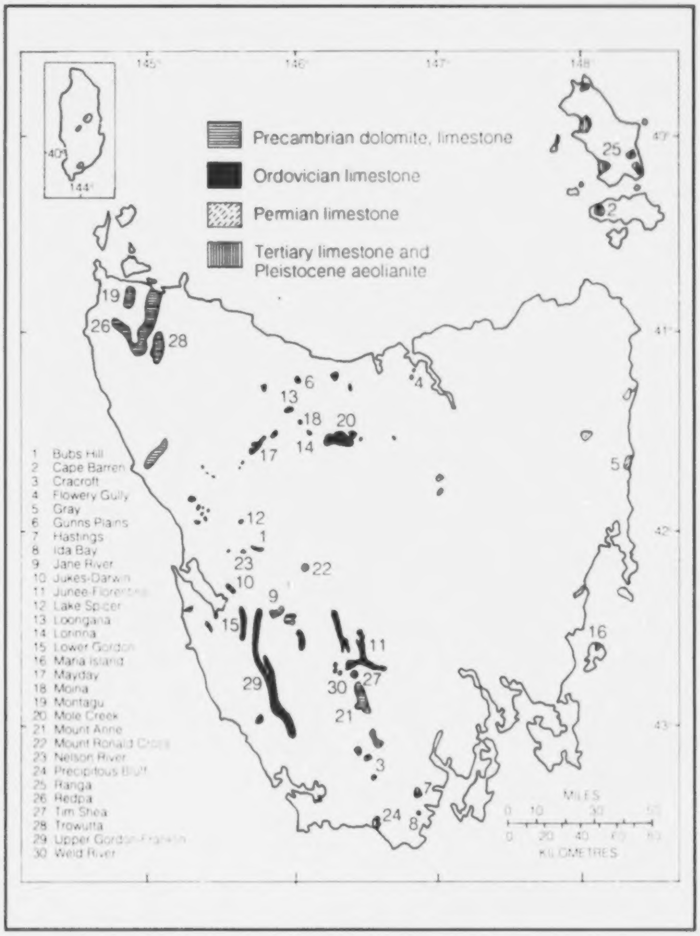
These ions may later be reprecipitated from water to form calcite deposits. Other acids, particularly humic acids from vegetation above the karst, will also cause solution of calcite and other carbonates.

Rates of solution vary drastically and depend on the interaction of a number of variables. Jennings (1971) reports rates of erosion of karst areas vary from less than 1 to up to 5000 m³/km²/yr.

An important variable is the **rate of flow of water.** This depends on the slope of the water table down to local base level, the surface relief, rainfall, the pre-existence of solution passages and the permeability and structure of the karst rock.

The **composition of the limestone** has a significant effect on solution rate, with a range of 60 to 90% calcite being best for karst development. This probably explains the poor karst development in the clay-rich Tasmanian Permian limestones and the selective development of karst in different horizons of Ordovician limestone. The **degree of jointing and fracturing** is important in carbonates with interlocking crystals (particularly dolomite).

Fig. 4.15: Distribution of karst areas in Tasmania.


145°
146°
147°
148°
40°
41°
42°
43°
144°
▤ Precambrian dolomite, limestone
■ Ordovician limestone
▨ Permian limestone
▥ Tertiary limestone and Pleistocene aeolianite
1 Bubs Hill
2 Cape Barren
3 Cracroft
4 Flowery Gully
5 Gray
6 Gunns Plains
7 Hastings
8 Ida Bay
9 Jane River
10 Jukes-Darwin
11 Junee-Florentine
12 Lake Spicer
13 Loongana
14 Lorinna
15 Lower Gordon
16 Maria Island
17 Mayday
18 Moina
19 Montagu
20 Mole Creek
21 Mount Anne
22 Mount Ronald Cross
23 Nelson River
24 Precipitous Bluff
25 Ranga
26 Redpa
27 Tim Shea
28 Trowutta
29 Upper Gordon-Franklin
30 Weld River
MILES
0 10 30 50
0 20 40 60 80
KILOMETRES

Climate is another factor affecting solution rates. In colder conditions, more carbon dioxide dissolves in water, but reaction rates are slower and solubilities generally lower.

Also significant is the **amount of material that the water is already carrying** in solution. This affects how much more material is dissolved by the water.

The presence or absence of **soil covers** and the **type and amount of vegetation** also influence solution rates.

Solution takes place in the vadose and phreatic zones, with most solution occurring near the water table where flow is greatest. In the lowest levels of the phreatic zone, water circulation is slow and karst development limited. Small networks initiated in the phreatic zone may later be enlarged following a lowering of the water table. Most caves in Tasmania occur close to the surface. Roberts and Andric (1974) were unable to find any deep phreatic or fóssil karst when drilling to check the water tightness of the H.E.C.'s proposed Gordon-above-Olga Scheme.

Surface features in karst areas

At Mole Creek (Fig. 4.16), folded Ordovician limestones are underlain by sandstones and conglomerates of the same age. Superficial slope deposits and stream deposits cover much of the area. The Mersey River is the only permanent stream crossing the broad limestone plain. Others go underground for at least part of their course. They disappear in **swallets** or **sinks** and reappear at **risings**. Tracing is often difficult, but the dye fluorescein has been used with some success.

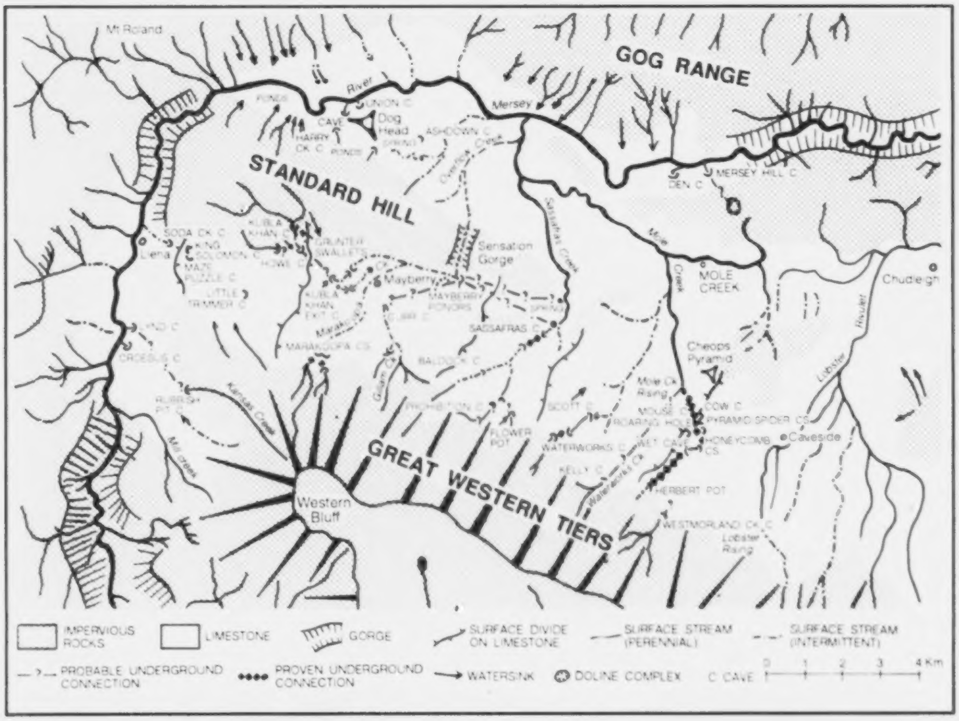

Mt Roland
GOG RANGE
River
Mersey
PONOR
UNION C
CAVE
Dog Head
HARRY CK C
PONOR
SPRING
ASHDOWN C
Creek
STANDARD HILL
DEN C
MERSEY HILL C
SODA CK C
Liena
KING SOLOMON C
MAZE
PUZZLE C
KUBLA KHAN C
GRUNTER SWALLETS
HOWE C
LITTLE TRIMMER C
KUBLA KHAN EXIT C
Mayberry
MAYBERRY PONORS
Sensation Gorge
Sassafras Creek
SPRING
SASSAFRAS C
Mole Creek
MOLE CREEK
Chudleigh
Rivulet
LAND C
CROESUS C
Marakoopa
MARAKOOPA CS
BALDOCK C
Gillam Ck
Cheops Pyramid
Lobster
Mole Ck Rising
MOUSE C
COW C
ROARING HOLE
PYRAMID SPIDER CS
RUBBISH PIT C
Kansas Creek
PROHIBITION C
SCOTT C
FLOWER POT
WATERWORKS C
WET CAVE
HONEYCOMB CS
Caveside
Mill creek
KELLY C
Waterworks Ck
HERBERT POT
Western Bluff
GREAT WESTERN TIERS
WESTMORLAND CK C
Lobster Rising
IMPERVIOUS ROCKS
LIMESTONE
GORGE
SURFACE DIVIDE ON LIMESTONE
SURFACE STREAM (PERENNIAL)
SURFACE STREAM (INTERMITTENT)
PROBABLE UNDERGROUND CONNECTION
PROVEN UNDERGROUND CONNECTION
WATERSINK
DOLINE COMPLEX
C CAVE
0
1
2
3
4 Km

Fig. 4.16: Drainage and associated karst features at Mole Creek.

Fig. 4.17: A doline developed in Ordovician limestone close to Sensation Gorge at Marakoopa.

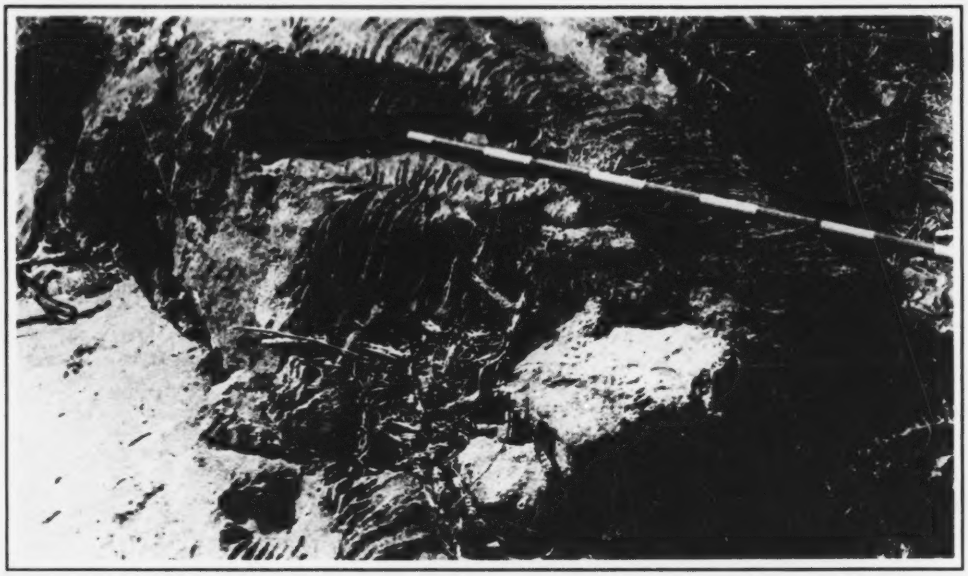


Fig. 4.18: Solution effects (rillen karren) on the surface of exposed limestone at Mole Creek.

Dry valleys are common and usually represent an initial phase of surface drainage on a former high-level surface. Underground flow is often marked by rows of **dolines** (Fig. 4.17). Some are produced by solution only, but many result from underground solution and subsequent surface collapse.

The Mayberry basin (Fig. 4.16) is one of the most interesting features in the Mole Creek area. Water is fed into the area from the higher regions (mainly Great Western Tiers). During wetter periods the doline complexes are full of water. In time of flood, water flows through Sensation Gorge into Overflow Creek. This is rare, and the water normally flows underground beneath a limestone divide, around the toe of the Standard Hill anticline and into Sassafrass Creek.

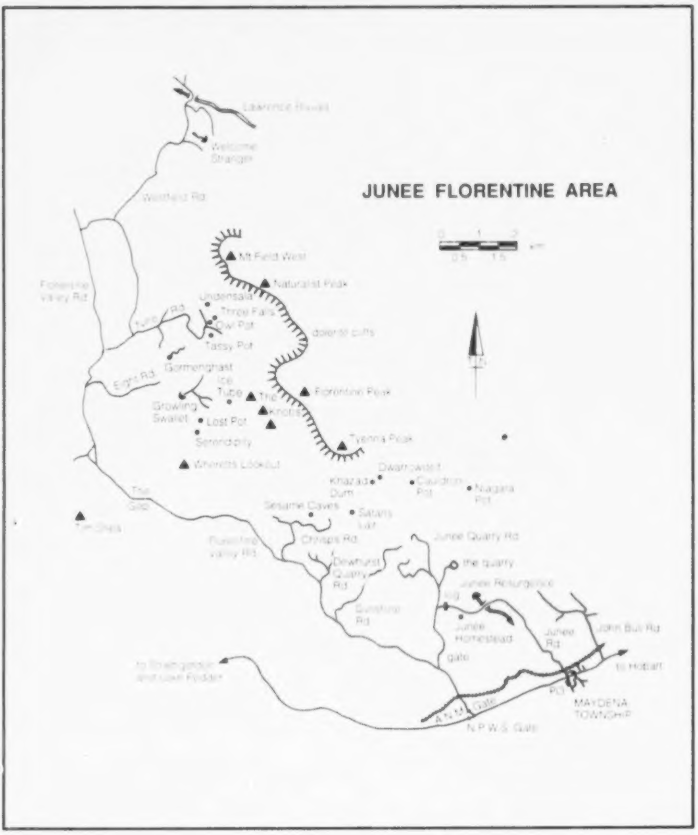
There is relatively little bare limestone at Mole Creek, most of it being soil-covered.

Figure 4.18 shows **rillen karren,** which is produced by the effect of rainfall on bare limestone. In Tasmania, **rund karren** (rounded solution grooves formed under a cover of soil or humus) are much more common.

The deepest cave in Australia, Anna Kananda (373m), occurs on the north-western ridge of Mount Anne. Other deep caves occur in the Junee area (Fig. 4.19).

Streams from the high areas of Wherrett's Lookout, Florentine Peak and Tyenna Peak, sink into Ordovician limestone at altitudes of about 700 metres. A major rising (known as the Junee Resurgence) emerges from Junee Cave at an altitude of 300 metres, five kilometres north-west of Maydena.

Fig. 4.19: Locality map of caves in the Junee Florentine area.

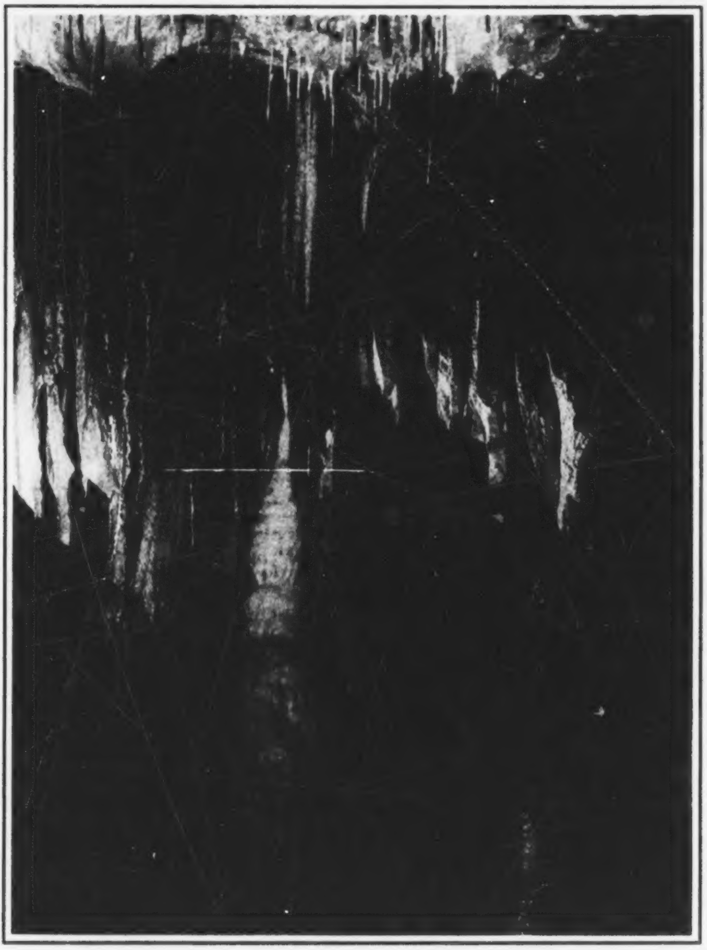

JUNEE FLORENTINE AREA
0
1
2
0.5
1.5
km
N
Lawrence Rivulet
Welcome Stranger
Westfield Rd
Florentine Valley Rd
Mt Field West
Naturalist Peak
Undensala
Three Falls
Owl Pot
Tassy Pot
dolerite cliffs
Gormenghast
Ice Tube
Growling Swallet
Lost Pot
Serendipity
The Knobs
Florentine Peak
Tyenna Peak
Wherretts Lookout
Dwarrowdelf
Khazad Dum
Cauldron Pot
Niagara Pot
Sesame Caves
Satans Lair
The Gap
Tim Shea
Florentine Valley Rd
Chrisps Rd
Junee Quarry Rd
Dewhurst Quarry Rd
the quarry
Junee Resurgence
log
Junee Homestead
Junee Rd
John Bull Rd
gate
to Strathgordon and Lake Pedder
to Hobart
A.N.M. Gate
N.P.W.S. Gate
PO
MAYDENA TOWNSHIP

In the Ida Bay area of southern Tasmania (Fig. 4.20), a breach of a major divide occurs where Mystery Creek flows into Entrance Cave under Marble Hill and out through Exit Cave into the D'Entrecasteaux River.

Cave deposits

The most common deposits in caves are those that have been washed in by streams or those that have fallen in by such processes as roof collapse. The best known deposits are the cave decorations that form by the slow dripping of water from cave ceilings. Calcium carbonate is precipitated to form **stalactites** (coming down from the ceiling), **stalagmites** (growing up from the floor) and **helictites** (complex, irregular and often delicate structures). Figure 4.21 shows spectacular decorations in one of the caves at Mole Creek and explains why they are so popular with tourists.

Fig. 4.21: Croesus Cave (Mole Creek).



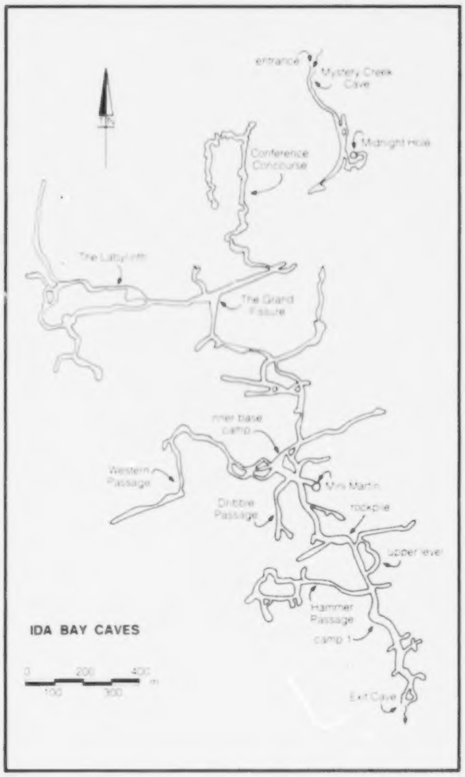

entrance
Mystery Creek Cave
Midnight Hole
Conference Concourse
The Labyrinth
The Grand Fissure
inner base camp
Western Passage
Mini Martin
Dribble Passage
rockpile
upper level
Hammer Passage
camp 1
Exit Cave
IDA BAY CAVES
0
200
400
m
100
300

Fig. 4.20: Map of caves at Ida Bay.

Cave sites and Aborigines

Caves are a fertile source of archaeological information because of their use by prehistoric people. Caves in Tasmania were used for shelter by Aborigines and native animals. Studies of the stone implements and bones found in cave deposits reveal a great deal about the culture and dietary habits of Tasmania's first inhabitants.

Clues about the surface environment are deduced from the bone fragments of animals that were part of the diet of the Aborigines and of the predatory marsupials. Other clues are provided by the types of fauna and flora that have fallen or been washed into the caves.

Chapter five

The development of rivers

Leon Walsh

Introduction

Flowing water is the most active agent of change on most parts of the Earth's surface. To a large degree it controls the development of the scenery as we see it today in Tasmania. Rivers, surface wash and the downhill movement of solid and weathered rock combine to remove the substance of the land and carry it to the oceans. Given enough time, flowing water can reduce the highest and most extensive land mass to heights little above sea level. Rivers are the routes by which excess water flows to the ultimate base level. Some of Tasmania's major rivers are shown in Figure 5.1.

When studying rivers we need to consider briefly some processes and effects of flowing water. We must also examine some basic questions concerning how water is concentrated into streams (water on slopes), and the features and effects of flowing water (water in channels).

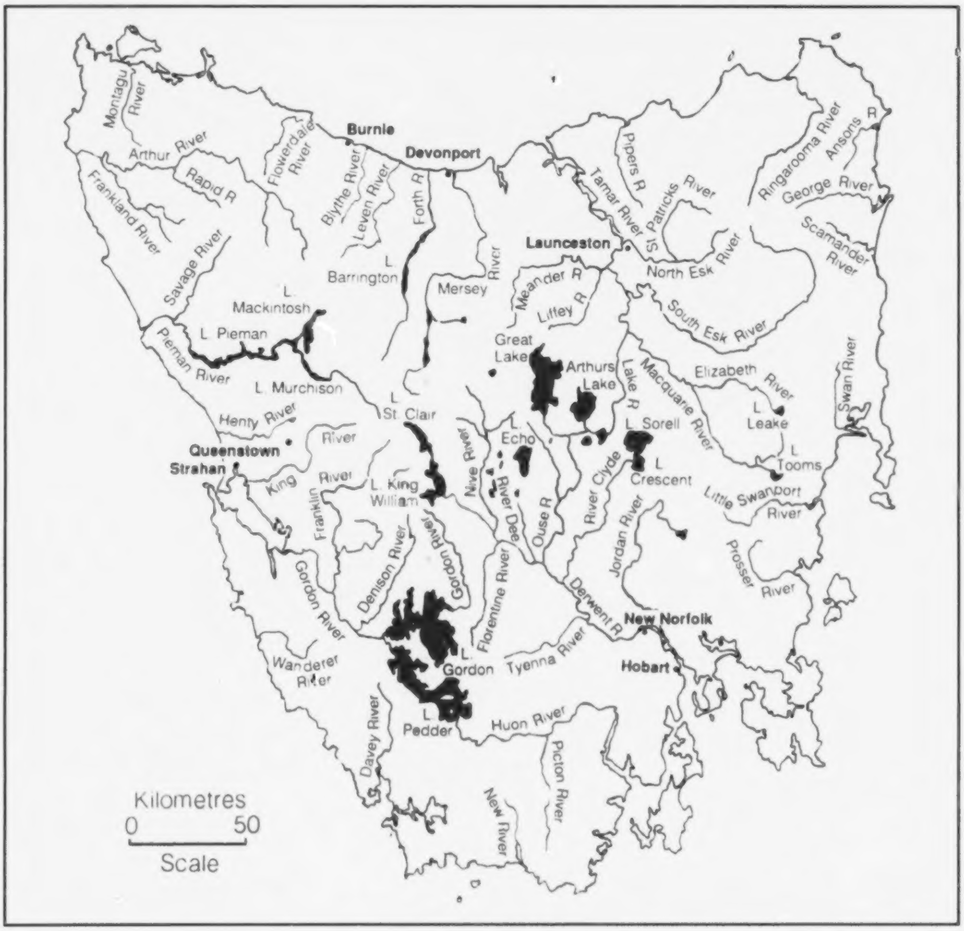

Montagu River
Arthur River
Rapid R
Frankland River
Flowerdale River
Burnie
Devonport
Blythe River
Leven River
Forth R
Savage River
L. Barrington
Mersey River
L. Mackintosh
L. Pieman
Pieman River
L. Murchison
Henty River
Queenstown
Strahan
River
King River
Franklin River
L. St. Clair
L. King William
Nive River
River Dee
Ouse R
Denison River
Gordon River
Gordon River
Florentine River
L. Gordon
Tyenna River
Wanderer River
Davey River
L. Pedder
Huon River
Picton River
New River
Launceston
Pipers R
Tamar River
St Patricks River
North Esk River
Meander R
Liffey R
South Esk River
Great Lake
Arthurs Lake
Lake R
L. Echo
L. Sorell
L. Crescent
River Clyde
Jordan River
Macquarie River
Elizabeth River
L. Leake
L. Tooms
Little Swanport River
Prosser River
Swan River
Ringarooma River
Ansons R
George River
Scamander River
Derwent R
New Norfolk
Hobart
Kilometres
0
50
Scale

Fig. 5.1: River locality map.

Water on slopes

Water which falls on hillsides, and does not infiltrate the ground or evaporate, moves down the slopes as overland flow until it becomes powerful enough to erode small channels or rills. Such rills may combine to form larger streams.

Water on slopes causes or aids various forms of erosion.

Water in channels

A river channel is formed and maintained by the flowing water it transports. Rivers evolve through geological time, and the processes of change that may be observed at present are the same processes by which they evolved.

Changes occurring during the history of a river may be brought about by changes in external conditions such as:

- *changes in climate (including glaciation);*
- *a change in elevation of the continent and related changes in vegetation;*
- *changes in the rate and type of weathering and in the amounts and kinds of material moving under the influence of gravity.*

A river channel cannot usually be spoken of as having been formed at a particular time — because frequently no evidence remains to tell us when it first developed.

From head to mouth the characteristics of a stream undergo changes. In general, in a wet environment, the trend of the changes could be shown as in figure 5.2.

Discharge

Discharge is a measure of a river's rate of flow at a given time, and is expressed as the volume of water passing a given point per unit of time — cumecs, or cubic metres per

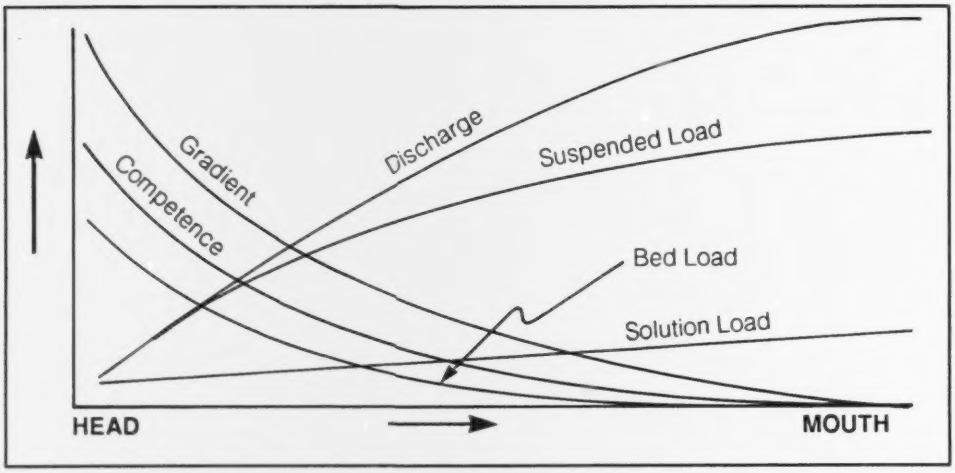


Fig. 5.2: Changes in stream characteristics from head to mouth.

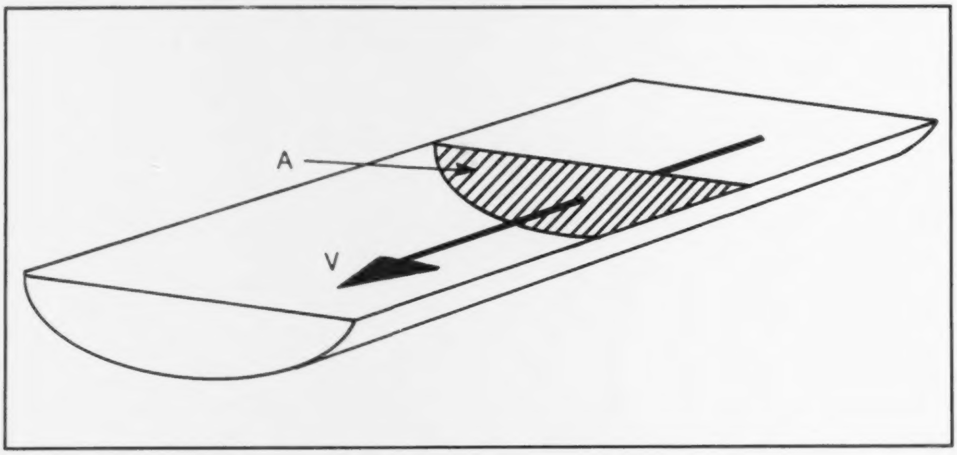


Fig. 5.3: Discharge, Q = Cross-sectional area (A) x the mean water velocity (V).

second. Discharge in humid areas increases downstream.

In practice the rate of discharge can be found by multiplying the cross-sectional area of the channel by the mean velocity of the water passing that point at that time.

Load

Load is the sediment transported by the river. It can be carried in three ways: as **dissolved load,** as **suspended load** and as **bed load.** Downstream the dissolved load (solution load) generally shows some increase, the suspended load increases a great deal and the bed load decreases.

Competence and capacity

There is an important distinction between competence and capacity. Competence is a measure of the largest particle that a stream can carry. Capacity is a measure of the total load a stream could carry. Competence depends largely on velocity and gradient; while capacity depends more on volume. For example, a small mountain torrent may be competent to move large boulders while lacking the capacity to transport a large quantity of sediment. The Mississippi River, on the contrary, lacks competence to move boulders in its lower reaches, but it has the capacity to carry the colossal load of some 500 million tonnes of sediment yearly to the Gulf of Mexico.

Velocity

Many of us like to think of a river in terms of its velocity — the wild, rapidly flowing mountain stream giving way to the deep, wide, placid, meandering river as it approaches the sea. Has it occurred to you that rivers actually speed up downstream? Consider the upper reaches of an 'average' river. The water may indeed race past your vantage point at breakneck speed — only to be caught in a pool or back-eddy further on. Even the velocity across a stream varies, with the water towards the middle flowing more rapidly than the water near the banks. Therefore we must consider average velocity.

In the past it was assumed that gradient was the dominant control on velocity, and that if the gradient decreased then so did the velocity. Research work undertaken since the 1950s by investigators such as Leopold and Maddock has shown this all-embracing concept to be wrong. Leopold and Maddock measured the velocity and discharge of the Yellowstone-Missouri-Mississippi River system and found that the downstream velocity increased as the discharge increased. An explanation of this is not easy for we must remember that rivers are like fingerprints — no two are identical. However in general, as the discharge increases downstream (as tributaries enter) and the stream channel widens and deepens, friction with the bed and banks becomes less effective in reducing velocity. This decrease in the effectiveness of friction more than compensates for the decrease in gradient, so average velocity increases.

Morphology (form) of channels

When viewed from above, or on a map, a stream presents a course which is **straight, meandering** or **braided**. Some rivers wind or meander sharply, others barely wind at all. A winding or meandering stream may be confined by valley walls, or spread over a flood plain. Braiding is the division of a single channel into two or more branching channels separated by alluvial channel deposits. Many rivers exhibit each of these three channel patterns somewhere along their lengths.

Straight channels

Straight channels seldom, if ever, occur for any length along a stream. Channel investigations have shown that even when the banks appear straight, the water in the stream is meandering, i.e. moving in a spiral or helical pattern downstream.

Meanders

It is one of the little understood characteristics of water that it flows in curving arcs or meanders. Even sediment-free streams flowing over glaciers develop meandering channels. And the Gulf Stream current is known to meander like a great river within the Atlantic Ocean.

Meanders commonly form in alluvium (stream-deposited material, usually unconsolidated) but they also form in other materials. In Tasmania, river meanders are common in all parts of the State.

Erosion occurs on the outside of the bend where the water velocity is high. On the inner bank water velocity is low and deposition takes place. The resulting deposits are called point bars.

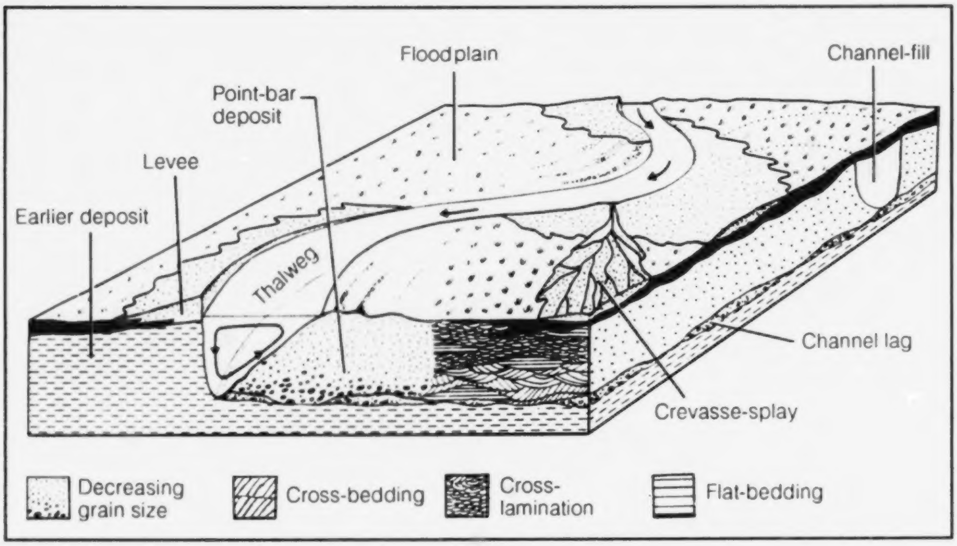

Flood plain
Channel-fill
Point-bar deposit
Levee
Earlier deposit
Thalweg
Channel lag
Crevasse-splay
Decreasing grain size
Cross-bedding
Cross-lamination
Flat-bedding

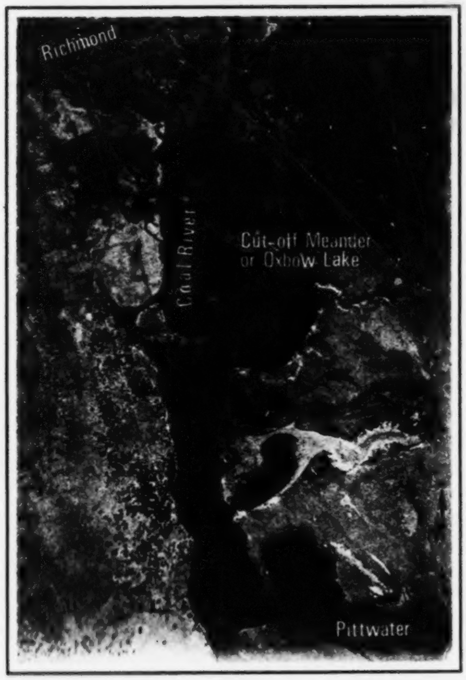
Fig. 5.4 River deposits.

Ox-bow lakes, or billabongs, occur when sudden changes in the course of the stream cut off part of the stream channel (Fig. 5.5).

Meanders have been studied in detail but little is known of their cause. Meandering may be inhibited by a heavy sediment load, a steep gradient and by some geological structures such as faults.

Braided channels

Fig. 5.5: A cut-off meander or ox-bow lake in the Coal River near Richmond.


Richmond
Coal River
Cut-off Meander or Oxbow Lake
Pittwater

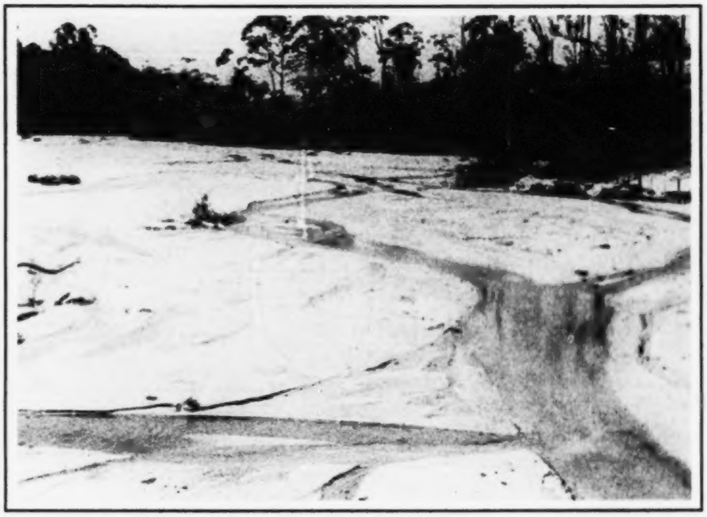


Fig. 5.6: A braided stream pattern on the surface of the delta on the Golden Fleece Rivulet, St Helens. Sediment was mainly derived from sluicing operations, further upstream, early this century.

Where a stream has abundant coarse sediment load and a steep gradient, it tends to develop a braided pattern; it develops two or more branching channels separated by channel bar deposits.

During a flood, heavy bank erosion and bed load transportation may occur. As the floodwaters lessen, the resultant sediments are deposited as channel bars. Braided stream patterns occur at St Helens where the Golden Fleece Rivulet enters the bay.

The work of rivers

Rivers require energy to do their work. They have both potential and kinetic energy.

A river's potential energy is converted into kinetic energy by its downhill flow. That kinetic energy is then mostly dissipated as heat due to friction from turbulent mixing and from contact with the bed and banks of the channel. The amount of heat(energy) loss caused by friction depends upon the roughness, straightness and cross-sectional form of the river's channel, as well as upon the amount of internal mixing of eddies. It is thought that more than 95% of a stream's energy is lost through friction. Energy which is not dissipated as heat is available for work, i.e. for erosion and transport.

Erosion

In streams, water is deflected from straight paths into a series of swirls and eddies, the type of movement being known as turbulent flow. This type of flow is highly effective in eroding a stream's channel. Figure 5.7 shows the approximate velocities that are needed to erode materials of various sizes (materials such as clay, silt, sand, pebbles and cobbles.) For example, sand-size grains may be eroded by a stream with a velocity as low as 20cms.

Increasing size of materials requires increasingly higher water velocities for transport. Higher velocities are also needed for transportation of clay-size particles. The reason for this is that the finer clay-size grains are resistant to erosion because of strong forces which bind the grains together. An additional factor is that the smaller grains make up the bottom of the channel and therefore the bed tends to be smooth. There are thus no protruding grains to aid the formation of local eddies or turbulence.

Certain sized grains, once eroded, are transported by water flowing at a much slower speed. For example, a water velocity of 20-100 cm/s may be needed to lift silt grains from the river bed, but they are kept in suspension by water flowing as slowly as 1 cm/s or less.

The diagram suggests that the greater part of the work of erosion by a river is done when the stream velocity is in the vicinity of 100 to 200 cm/s; that is in times of flood or in certain portions of the river, for example, in rapids.

Transportation

Figure 5.7 illustrates that it requires lower stream velocity and hence less energy to keep a particle in motion than it does to erode the particle and start it moving. The load that a stream carries at any one time is usually less than its capacity because there is usually insufficient material of the required size range available.

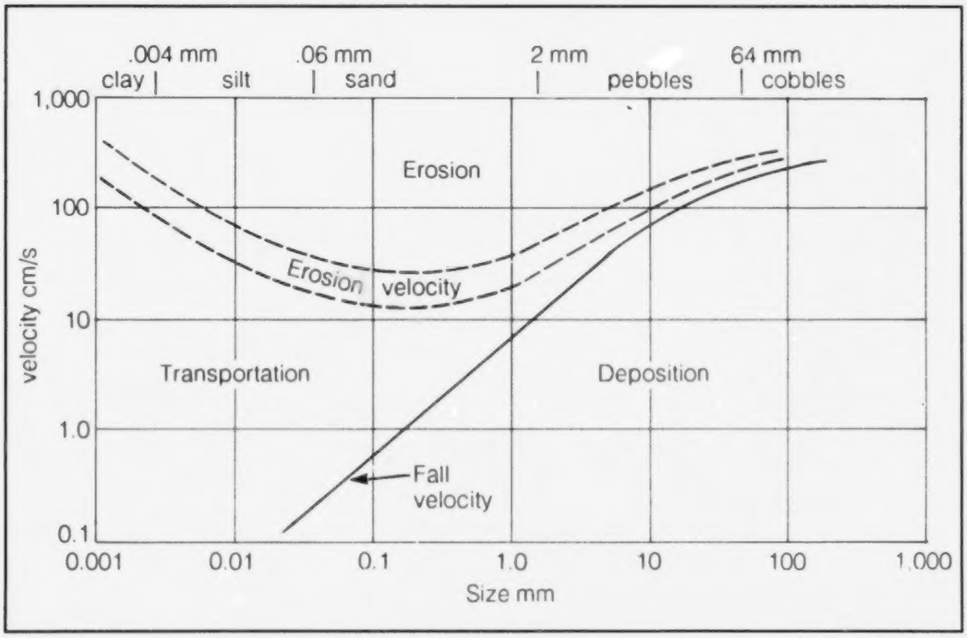


Fig. 5.7: Curves of erosion and deposition for uniform material. Erosion velocity shown as a band.

A river transports material in three ways: in **solution**, in **suspension** and as **bed load.**

- **Material in solution**
  This involves the material carried off by the corrosive action of the water. Bicarbonate, sulfate, and chloride ions make up the majority of the negative ions carried by most rivers, with calcium and sodium being the important positive ions. Together, these five ions make up 90% or more of the dissolved load of most rivers. Silica, potassium and magnesium, the most abundant of the minor constituents, generally make up less than 5% each.
- **Material in suspension**
  Clay particles are easily carried because their diameter is less than 0.004 mm. They will stay in suspension for days, but are rapidly precipitated in estuaries where the water becomes saline. Larger particles are carried in suspension through water turbulence. The turbulence creates a suction effect which lifts the particles off the bed of the stream. Turbulence usually increases in flood time.
- **Material transported as bed load**
  By this process a particle jumps from one point on the stream bed to another (**saltation**), or moves forward along the stream bed — either by rolling or sliding (**traction**).

Nature and quantity of load

The load depends not only on the carrying capacity of the river, but also on the availability of material. Thus a river flowing across granite carries sand in suspension, and larger pebbles by traction and saltation. In contrast a river flowing across limestone carries much calcium bicarbonate in solution, as well as mud (from impurities in the limestone) in suspension.

The quantity of material that a river transports in a year may be estimated approximately. It is very difficult to measure the bed load, whereas the suspended and dissolved loads can be more easily measured. Even so, the estimates made on some U.S.A. rivers show that the proportions of load carried by the different methods vary from time to time and place to place.

Nevertheless the order of magnitude of these estimates may be surprising. For example, the Mississippi River pours approximately 500 million tonnes of material into the Gulf of Mexico each year:

- Load in solution: 100 million tonnes per year
- Load in suspension: 370 million tonnes per year
- Traction, saltation load: 30 - 40 million tonnes per year

A research worker in Tasmania (Olive, 1974) studied the suspension and solution load in three rivers in south-east Tasmania during the period July 1969 to June 1970.

From samples taken at carefully selected times and locations, he was able to estimate total loads carried by the streams over the year.

Fig. 5.8: Suspension and solution load in rivers in south-east Tasmania (reference is made to wash load which is the combination of both suspension and solution loads).

RIVER	AREA OF CATCHMENT (KM^2)	ESTIMATED TOTAL SUSPENSION LOAD FOR ONE YEAR (tonnes / year)	ESTIMATED TOTAL SOLUTION LOAD FOR ONE YEAR (tonnes / year)	ESTIMATED TOTAL WASH LOAD (tonnes / year)	ESTIMATED EROSION RATE (tonnes of wash load per km^2 per year)
SNUG RIVULET	19	216	867	1083	57
BROWNS RIVER	13	129	482	611	47
MOUNTAIN RIVER	40	298	1662	1960	49

The solution load was particularly dominant, making up approximately 80% of the total wash load in the three streams. It should also be noted that the erosion rates are similar — despite differences in the environments of the three catchments. It should also be noted that these figures are typical of many rivers in the wetter parts of Eastern Australia.

It has been estimated that the Junee River, above its confluence with the Tyenna River near Maydena, carries about 2500 tonnes per year of limestone in solution.

Deposition of material

A stream begins to deposit its load when its flow velocity falls below the level needed to transport the material. It is a selective process. At first the coarsest material settles out and then as the velocity continues to decrease finer and finer material is deposited.

The major factors that cause a river's velocity to decrease and which therefore encourage deposition, are: **reduction in slope, decrease in rate of flow**, and **increase in frictional force**.

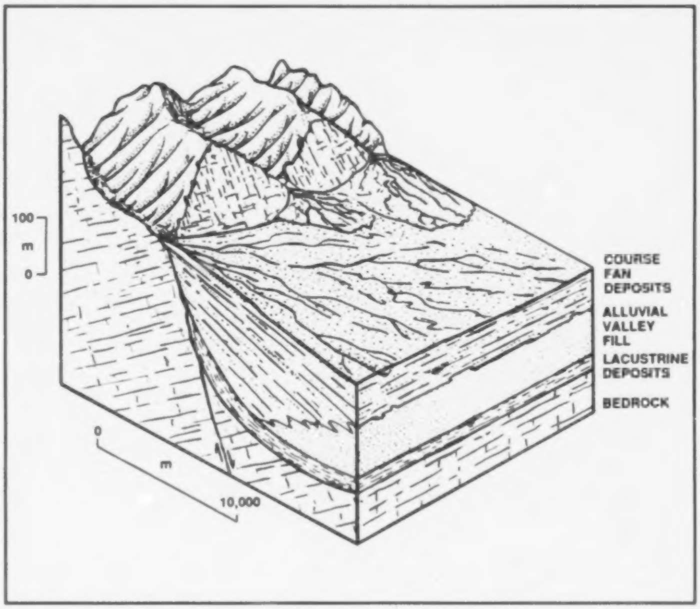
Depositional landforms

In the upper reaches of a stream, marked irregularities in gradient are common. As a stream passes from a steep slope onto a gently sloping surface, there is a loss of energy and a consequent reduction in competence. Thus a stream heavily loaded with material ranging from clay to boulders may change over a short distance so that it is capable of transporting only the finer material.

Alluvial fans

When there is a sudden loss of competence, such as when a stream enters another stream, unsorted mudflow deposits or poorly sorted alluvial deposits are laid down producing a fan-shaped feature known as an alluvial fan (Fig. 5.9). An excellent example of an alluvial fan may be found at the junction of the Nile River and the South Esk River. The Nile River flows down from Ben Lomond and on reaching the flat floor of the South Esk Valley suffers a sharp decrease in competence, and a typical fan like deposit has resulted. Other examples include Dean Brook and Millvale Creek flowing into the Derwent River upstream from Bridgewater.

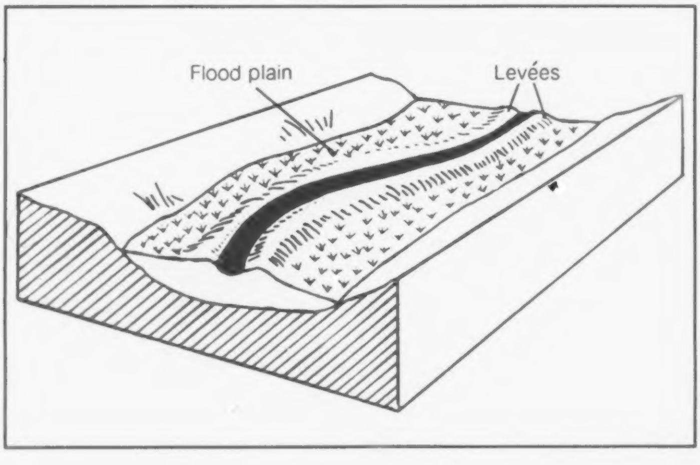
Fig. 5.9: An alluvial fan is formed due to a loss of competence resulting from a decrease in slope. The deposit is poorly sorted and distributaries are common.



Flood plains

During times of flood, the competence and volume of a stream increase. The water in the channel rises until it begins to pour over the edge in a thin sheet. Friction against the bottom then becomes significant and, as a result, the competence decreases and deposition takes place. Coarser material is deposited on the ridges (or natural levees) either side of the stream and finer material is deposited across the surrounding flood plain (Fig. 5.10).

Fig. 5.10: The flood plain of a river with natural levees. The flood plain is often marshy, the water table being near the surface.



Behind the Scenery

Many Tasmanian rivers do not possess prominent levees. Deposition takes place on the inside of meanders and the channel position changes leaving a series of low ridges on the flood plain.

1953

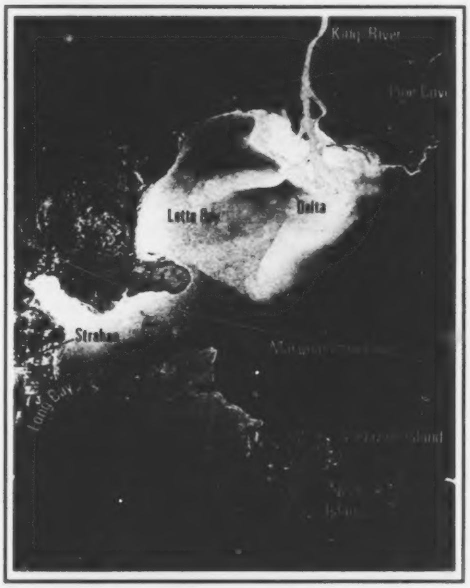
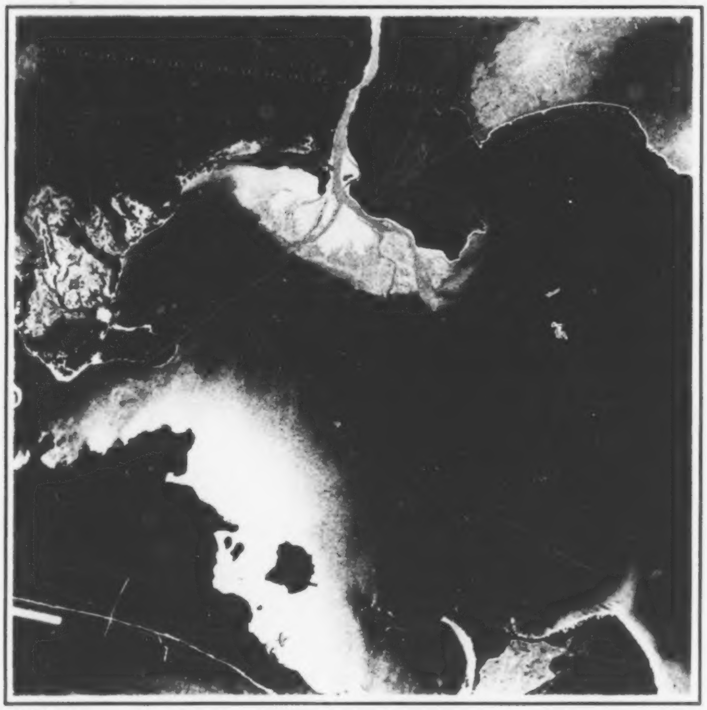


Fig. 5.11: The King River entering Macquarie Harbour in 1953 and 1981 showing the growth of the delta.



1981

Deltas

Deltas are deposited when a sediment-laden stream flows into a body of standing water such as a lake or ocean. A number of Tasmanian Rivers exhibit deltas. The King River on entering Macquarie Harbour drops most of its load forming a deltaic deposit (Fig. 5.11). The Leven, Forth and Mersey Rivers in north-western Tasmania have **estuarine deltas**.

Estuarine deltas form in part from the chemical effects that occur when river water meets sea water. When river water meets sea water, the ions of the salt water adhere to the surfaces of colloidal clay minerals, causing them to **flocculate** and settle out from suspension. Unlike the situation in alluvial fans, the loss of competence in the formation of these deltas is gradual and this is reflected in sorting rather than chaos. An estuarine delta occurs on the Derwent River, a little above Bridgewater. The deposits are called 'deltas' because many of them resemble the Greek letter delta(Δ).

Drainage patterns

Many drainage patterns have been recognised and described, but the most common in Tasmania are **dendritic, trellis** and **rectangular** patterns. In reality many streams in Tasmania result from combinations of these patterns, producing what some would call 'complex patterns'.

Dendritic or branching patterns are very common and usually occur on easily eroded flat-lying sediments. In Tasmania the dendritic pattern is often developed on the near-horizontal Permo-Triassic sedimentary rocks.

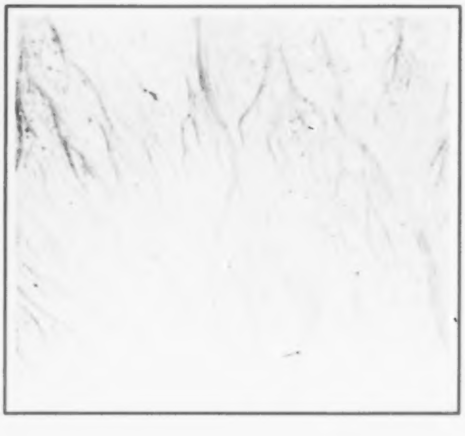


Fig. 5.12: A dendritic drainage pattern developed on the beach just east of Fossil Bluff at Wynyard. This pattern was caused by water flowing back to the sea.

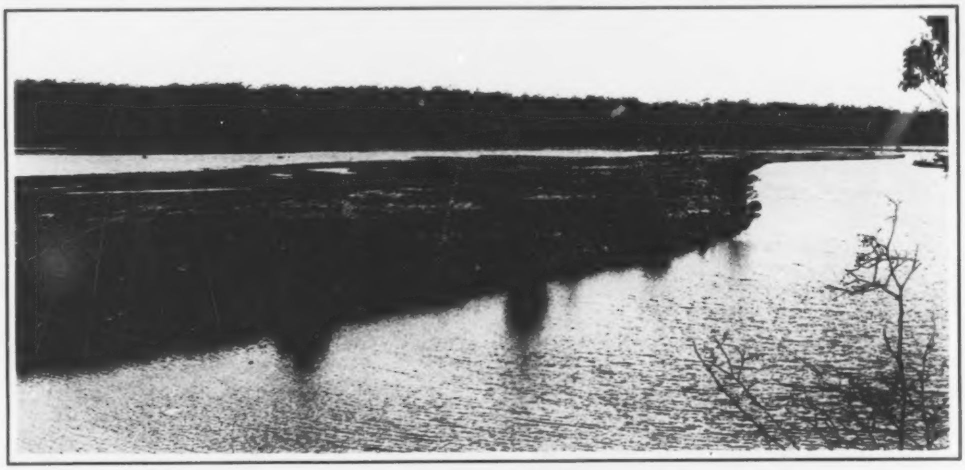


Fig. 5.13: Part of the delta of the Scamander River. A minor levee bank has developed — the only place trees grow because of the better drainage.

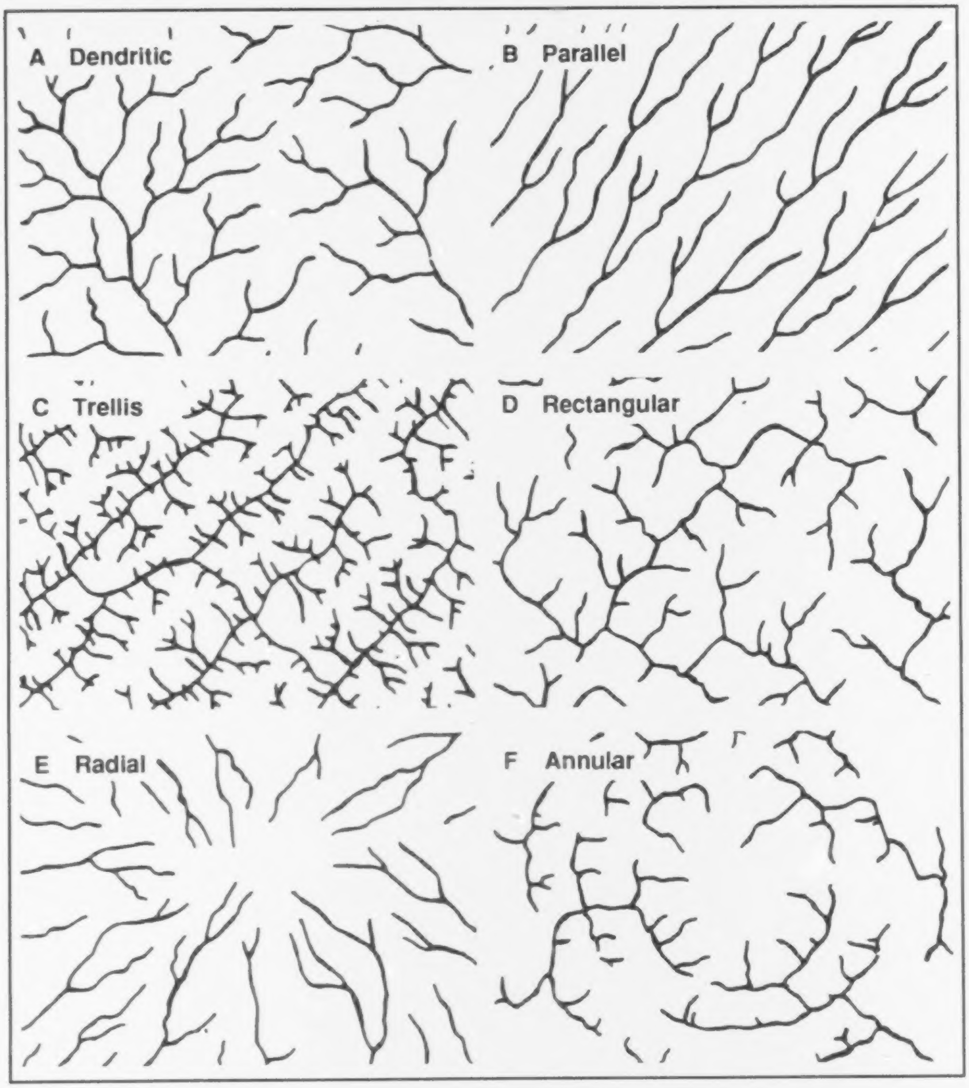

A Dendritic
B Parallel
C Trellis
D Rectangular
E Radial
F Annular

Fig. 5.14: Drainage patterns, each of which can occur at a variety of scales.

Trellised patterns result when stream courses are directed by differences in the structure and character of the bedrock formation. In an area of dipping beds, (including areas of folded rocks) streams eroding weaker or softer beds parallel to the strike may join with streams which are flowing parallel to the dip to form a trellised pattern (Fig. 5.15).

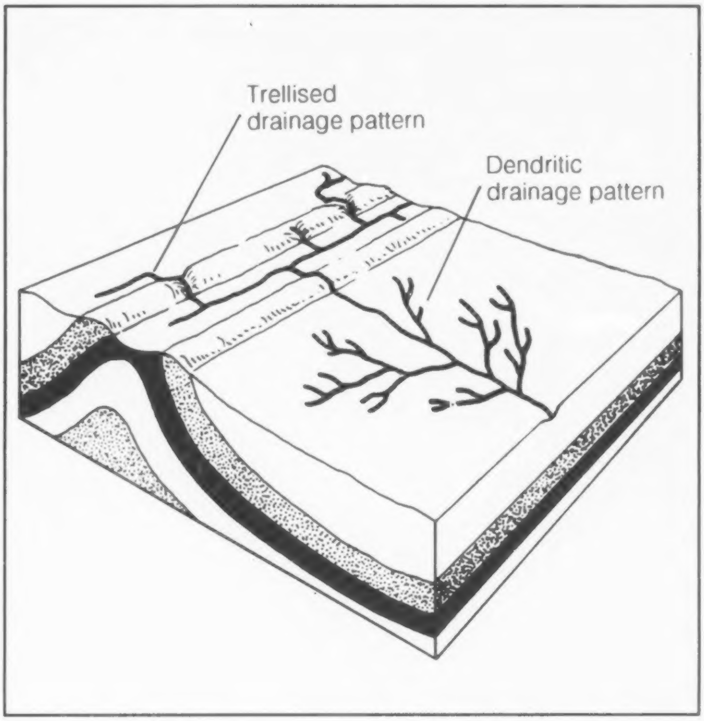


Fig. 5.15: Dendritic and trellised drainage patterns.

The course of the Florentine River is controlled by both rock structure and rock type. The folded, resistant rocks of the Tiger Range not only constrain the river to the west but also provide several tributaries in a trellised pattern. To the east, the valley is bounded by the resistant Jurassic dolerite of Mount Field West and the Misery Range. Within these boundaries, the Florentine River has etched its course through less resistant limestone, at times disappearing in sink-holes only to re-emerge downstream.

Rectangular patterns occur when the stream course is controlled largely by joint and fault systems in the rocks. Here the stream erodes along the line of weakness, sometimes changing direction at right angles. This pattern tends to occur in small localized areas such as the jointed dolerite of the Central Highlands to the east of Cathedral Mountain.

Complex patterns

Most stream patterns in Tasmania have resulted from interaction of both variations in rock type and the presence of joints or faults.

The Arve River follows a relatively straight course through the jointed dolerite, then develops a prominent meander belt in soft Permo-Triassic rocks until it reaches more resistant Permo-Triassic rocks where it is forced to follow a straighter course (Fig. 5.16).

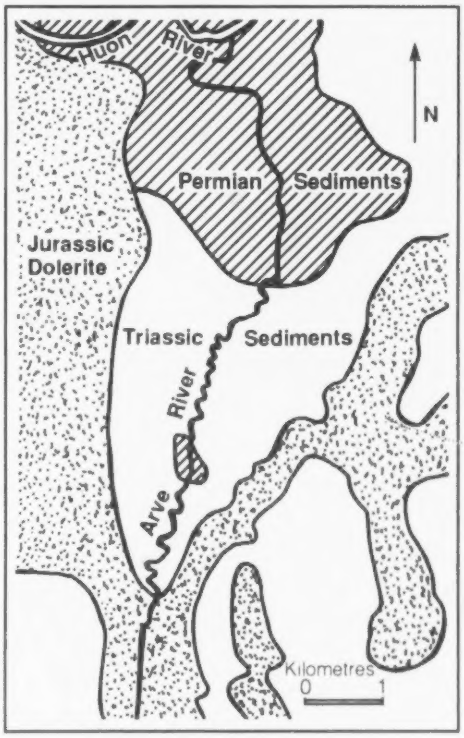


Fig. 5.16: Control of course of the Arve River by the underlying rock.

The Mersey River between Standard Hill and Alum Cliffs follows the **axis of a syncline** in folded Ordovician Gordon limestone (Fig. 5.17).

Large-scale faulting has had a dramatic influence on drainage patterns in several areas of Tasmania. The Tamar and Derwent Rivers began as interconnected lakes in downthrown grabens caused by large-scale normal faulting in the Tertiary. The same faulting episodes produced the downthrown blocks of Great Oyster Bay on Tasmania's east coast and Macquarie Harbour to the west.

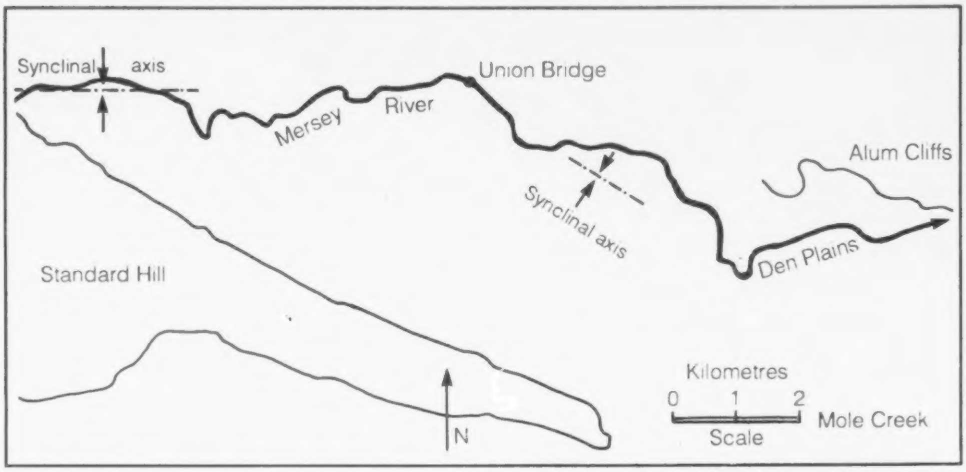


Fig. 5.17: The Mersey River between Standard Hill and Alum Cliffs is controlled by a syncline in Ordovician limestone.

Superimposed patterns

In many regions ancient folded rocks, which were formerly hidden beneath a cover of younger sedimentary layers, are now exposed. The rivers initiated on the cover with a drainage pattern appropriate to the structure of the cover. They eventually cut their valley into the underlying rocks, maintaining their courses with little or no relation to the very different structures over which they now flow. Such streams are called superimposed streams.

A superimposed stream is often independent of present structural control. The river has been able to maintain its course across resistant structures such as ridges, because it started as a stream on younger rocks which have been eroded away. Thus, the stream is let down or superimposed on the underlying structure.

Nye and Blake as far back as 1938 realised that the Tasmanian drainage system is largely superimposed on the Jurassic dolerite, Palaeozoic and Precambrian sediments.

In the Leven Canyon, the Leven River is superimposed on the folded Palaeozoic rocks.

Longitudinal profiles

Streams tend to erode the steepest parts of their channels and build up the gentle parts to a single uniform gradient. This intuitive observation is based on research which has led to the notion that a stream tends to equalise its work in all parts of its course. Hence,

Fig. 5.18: The deep gorges along parts of the Gordon River have formed as the river has cut down into older Precambrian and Palaeozoic rocks.

Fig. 5.19: The Leven River superimposed on folded Ordovician rocks.

if a stream is carrying all the material it is competent to transport, there is no erosion of the channel. If it has less than a full load, it takes up more by erosion of its bed.

Thus a stream's longitudinal profile (or slope of the channel from head to mouth) tends to acquire a smooth shape, concave upwards, by wearing away abrupt sections and filling in low spots. The lower end of this smooth curve is base level. For rivers, there is a general base level in the sea, but lakes or sharp decreases in gradient may form local base levels.

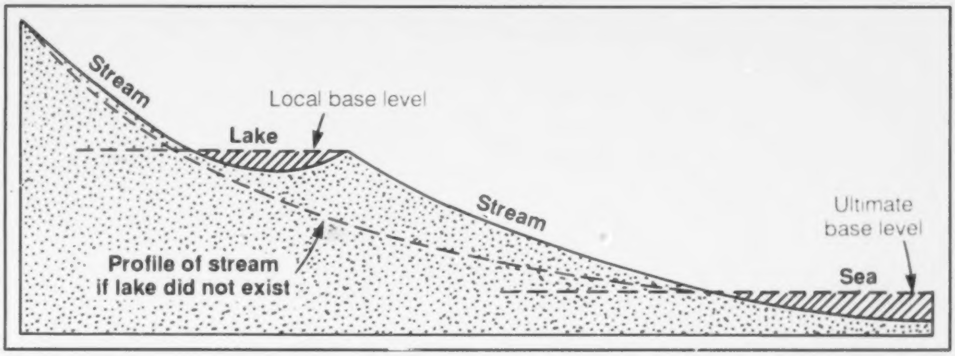


Fig. 5.20: The long-profile of a stream showing its relationship with local and ultimate base-levels.

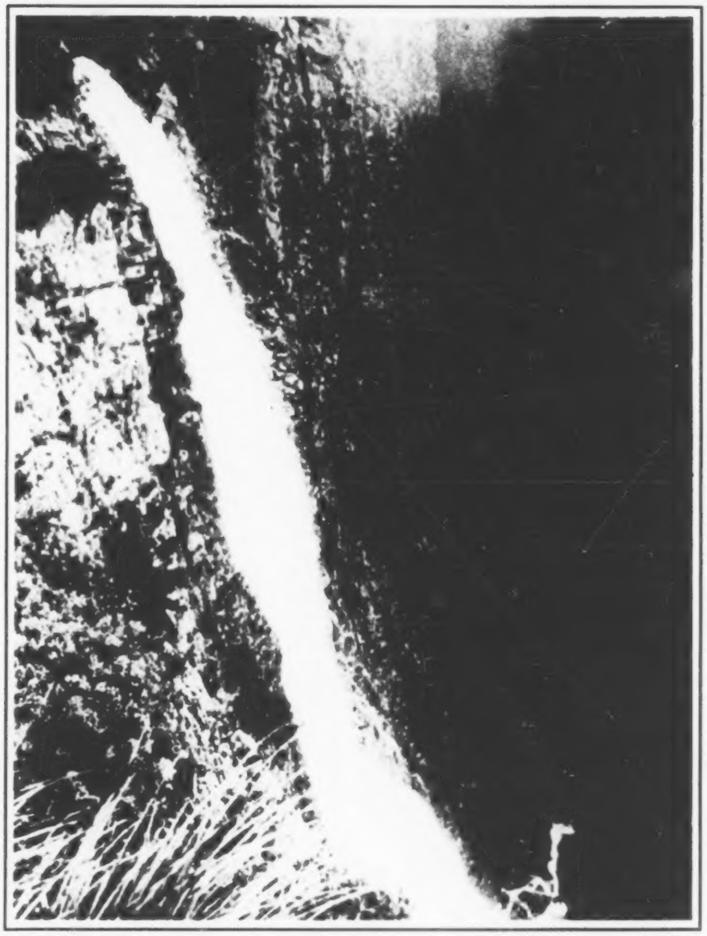


Fig. 5.21: Spectacular Falls—Mount Anne in S.W. Tasmania.

Interruptions to the long profile

Irregularities or changes in the longitudinal slope can occur:

- where streams flow over rocks of differing resistance;
- when the drainage system has been rejuvenated by earth movements or by a fall in the sea level.

Waterfalls, rapids, entrenched meanders and terraces are some of the landforms and features associated with interruptions to the long profile of a stream.

Waterfalls and rapids

Waterfalls are sharp breaks in the long profile of a river, where the water drops for a vertical distance in one fall. Rapids are sections of the long profile in which the flow of water is broken by short vertical drops. Tasmania has a large number of spectacular waterfalls (Fig. 5.21).

Many waterfalls owe their presence to variations in geological structure and rock type. The Montezuma Falls, along the route of the old north-east Dundas tramway, plunge over a fault scarp. Another Tasmanian waterfall which owes its origins to a rock fault is found in the upper reaches of the Mersey River. The river runs over the edge of a resistant dolerite sill which is faulted against less resistant Triassic sediments. The river has been able to excavate the sediments and plunges over the near-vertical fault scarp just below Junction Lake.

At Russell Falls (Fig. 5.22) in the Mount Field National Park the water plunges over a cliff developed in Permian mudstone. These near horizontal rocks have vertical joints and alternations of hard and soft layers. The combination of these factors is responsible for the presence of the waterfall. Waterfalls of similar origin are located at Fern Tree and in the valley of the Upper Mersey near Cathedral Mountain.

Waterfalls also occur where larger rivers have cut their courses to a lower level than a smaller tributary flowing into it. This may be related to their relative energy levels or the presence of resistant rocks in the bed of the tributary. Examples of these can be found where the Yolande River enters the Henty River and at the Forth Falls, east of the town of Wilmot.

Waterfalls are commonly found in glaciated districts where overdeepening of the main valley leaves hanging valleys above the main floor (Fig. 5.23). Valhalla Creek and V.C. Falls in Mount Field National Park are excellent examples of this type.

Entrenched meanders and terraces

When a land surface is uplifted, a river is raised further above its base level, and it must begin lowering its course. Such a river is said to have been **rejuvenated.** More energy is available to the stream, and features such as gorges, canyons and rapids reappear.

A river with an already established flood plain may cut through its own deposits into the underlying rocks when the land surface is uplifted and the river is rejuvenated. The sides of the original flood plain deposit then remain as flat terraces above the new level of the river. However, many terraces are not due to rejuvenation but are the result of **valley deposition.**

Valley deposition occurs as a result of a change in climate. In a cold phase streams fed by melting glaciers can carry substantial loads of sediment. In the following warmer climatic phase the river carries much less sediment and deposition occurs.

Fig. 5.22: Russell Falls near the entrance to Mount Field National Park. The 35metre falls plunge over jointed Permian Fern Tree Mudstone.

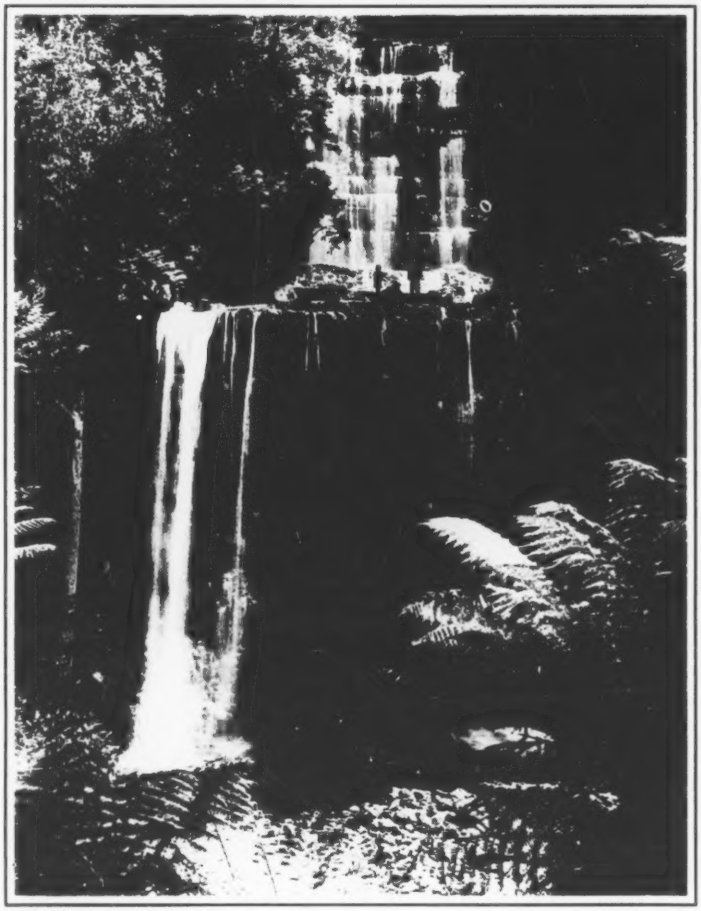


Fig. 5.23: Small glaciers do not cut their valleys as deeply as large glaciers. When the ice melts a waterfall may result at the junction of two such glaciers.

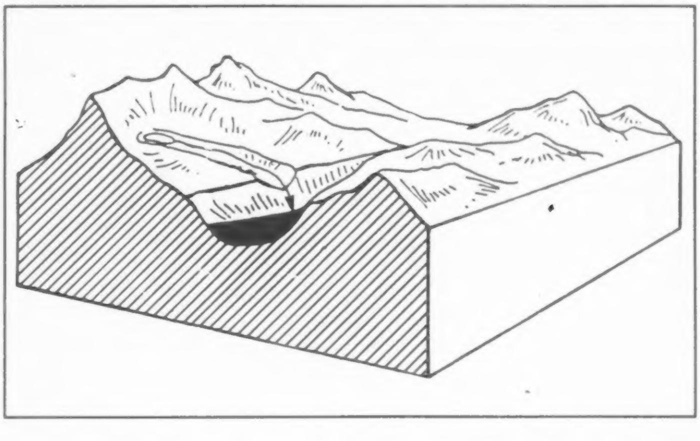
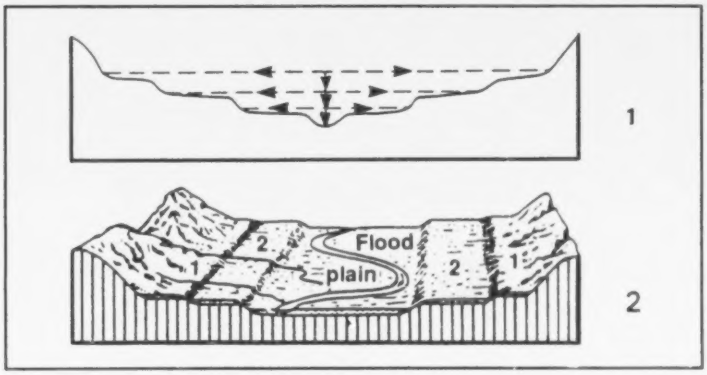


Fig. 5.24: A cross-section and oblique view showing paired river terraces on a flood plain.



Terraces are widespread along Tasmanian rivers, for example near Native Plains on the Mersey River and at Macquarie Plains and Ouse on the Derwent River.

The terraces in the Mersey Valley suggest that at some time in the past levels were higher than they are now. Changes in sea level also caused the formation of terraces on the lower Pieman River, while terraces further upstream are the result of climatic fluctuations.

Again, if such a river has a meandering course before rejuvenation, the winding channel is deepened and the old meanders become entrenched or incised. Several of the spectacular gorges found in Western Tasmania are evidence for superimposition rather than rejuvenation.

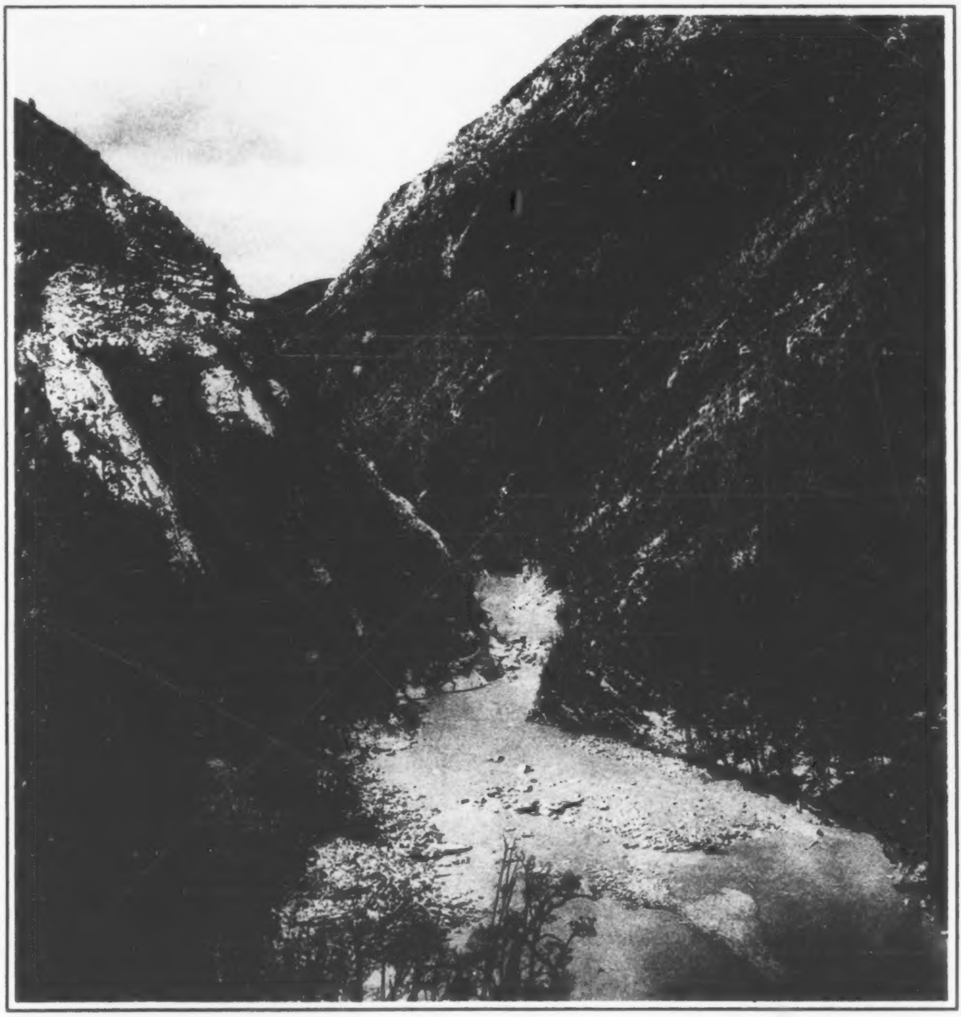


Fig. 5.25: The King River Gorge from the old railway line between Queenstown and Strahan.

River capture

In the process of valley development, all streams continue to extend or modify their drainage basins. During this process it may happen that one river finds more favourable conditions for growth and extension than does another, on the opposite side of a divide. By the extension of its tributaries, this stream cuts back until it captures some of the headwaters of the less favourably disposed stream and diverts them into its own channel. Such a phenomenon is called stream piracy or river capture, and the stream whose territory has been captured is said to have been beheaded by the pirate stream.

The conditions which give a stream an advantage over a neighbouring stream may be listed as follows:

- a greater volume of water;
- softer rocks in which to excavate its channel;
- a steeper gradient.

There are many well documented cases of river capture in Tasmania. The selected examples which follow describe stream piracy that has occurred in the past, and possible stream piracy that will occur in the future.

The history of the Florentine River valley affords an excellent example of river capture (see Figure 5.26). The Florentine River once flowed into the Gordon River by way of the south end of the Tiger Range (a course opposite to that of the present). However, the development of the Gordon and its tributaries was slowed by a resistant bar of Ordovician conglomerate between The Thumbs and Mount Wright (the site of a gorge 200 metres deep in the Gordon River at the present time). Eventually a tributary of the Derwent cutting back from the north captured the Florentine as it could cut down into dolerite more rapidly than the Gordon could cut through the conglomerate. This capture progressed down the Florentine Valley and completely reversed the drainage.

Nicolls (1960) has shown that the stream pattern of the Liffey River near Bracknell indicates that a river capture took place at some earlier time. Whitemore Creek appears to be a former course of the Liffey River, and in fact, in times of flood some of the water of the Liffey still goes this way. In his paper, Nicolls shows that from water level at a point on the Liffey River, only a low bank interrupts a continuous fall of 18 metres to another point at the head of the Whitemore valley. Whitemore Creek may, in the future, again carry the waters of the Liffey (Fig. 5.27).

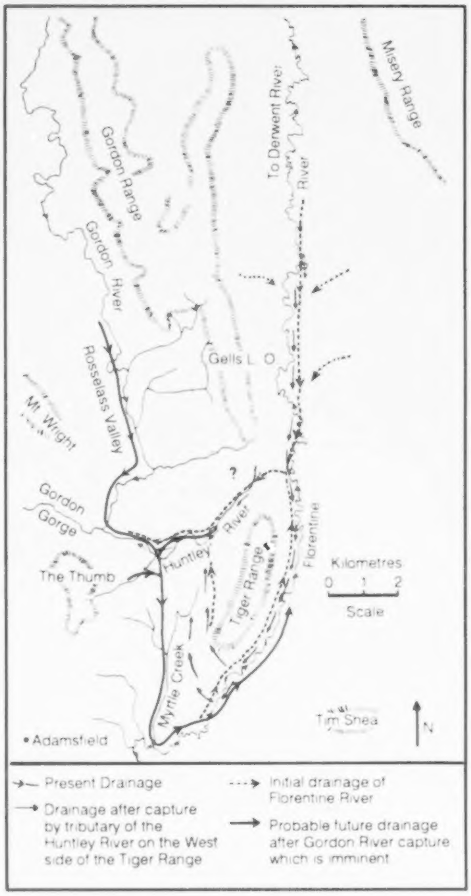

Misery Range
To Derwent River
River
Gordon Range
Gordon River
Rosselass Valley
Gells L.
Mt Wright
?
Gordon Gorge
Huntley
River
Tiger Range
Florentine
The Thumb
Myrtle Creek
Kilometres
0 1 2
Scale
Tim Shea
N
• Adamsfield
Present Drainage
Initial drainage of Florentine River
Drainage after capture by tributary of the Huntley River on the West side of the Tiger Range
Probable future drainage after Gordon River capture which is imminent

Fig. 5.26: The Florentine River once flowed in the opposite direction to the present. The capture of the Gordon River via Huntley Creek and Myrtle Creek into the Florentine River and then to the Derwent River is geologically imminent.

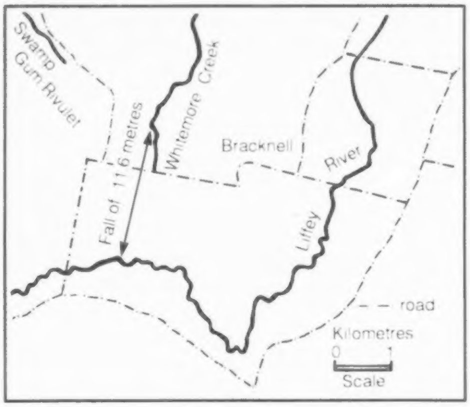

Swamp Gum Rivulet
Whitemore Creek
Fall of 11.6 metres
Bracknell
River
Liffey
road
Kilometres
0 1
Scale

Fig. 5.27: River capture near Bracknell. Whitemore Creek and Swamp Gum Rivulet are probably former courses of the Liffey River.

The impending capture of the South Esk River by tributaries of the North Esk River near Evandale is a spectacular example of river capture. This was noted by Nye and Blake in 1938 and by Carey in 1946. A tributary of Rose Rivulet (itself a tributary of the North Esk) has almost breached the divide between the North and South Esk. The tributary has eroded through the divide of unconsolidated Tertiary clays and sands and thin basalt capping.

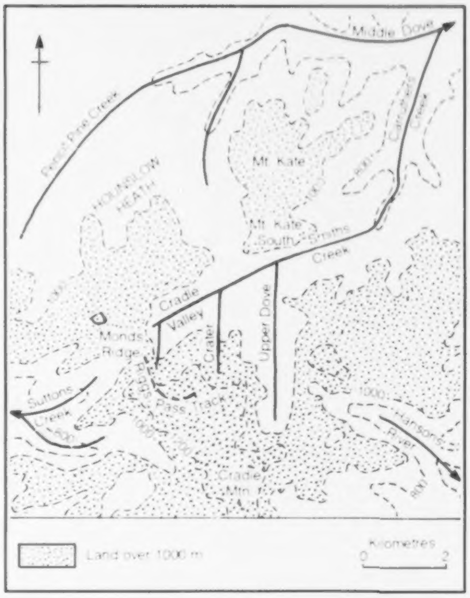

Middle Dove
Pencil Pine Creek
Carruthers Creek
Mt Kate
800
1000
HOUNSLOW HEATH
Mt Kate South
Smiths Creek
Cradle Valley
Monds Ridge
Crater
Upper Dove
Suttons Creek
Riggs Pass Track
1000
700
Hansons River
Cradle Mtn
Land over 1000 m
Kilometres
0
2

Fig. 5.28a: Reconstructed preglacial drainage routes in the Cradle Mountain area.

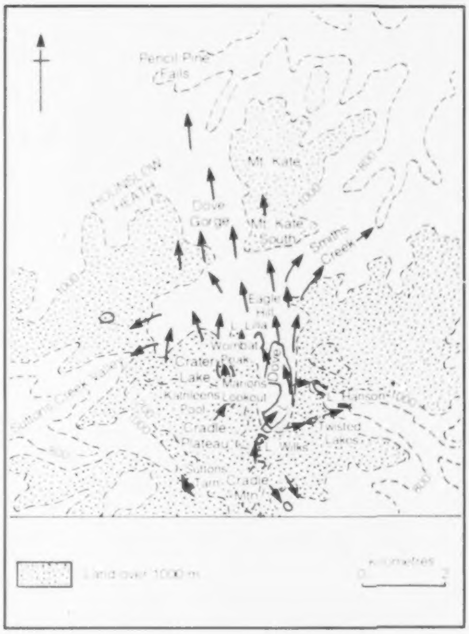

Pencil Pine Falls
Mt Kate
800
1000
HOUNSLOW HEATH
Dove Gorge
Mt Kate South
Smiths Creek
Eagle Hill
L. Lilla
Wombat Peak
Crater Lake
Marions Lookout
Dove
Kathleens Pool
L. Hanson
Cradle Plateau
Twisted Lakes
L. Wilks
Suttons Creek Valley
Suttons Tarn
Cradle Mtn
Land over 1000 m
Kilometres
0
2

Fig 5.28b: Late Pleistocene ice flow directions in the Cradle Mountain area.

Diversion of drainage by glaciation

The Pleistocene glaciation of the Central Plateau and West Coast Ranges of Tasmania caused many small scale diversions of parts of pre-existing drainage systems.

Colhoun (1980) noted that, "...one of the best examples occurs in the Cradle Mountain National Park on the north-western part of the Central Plateau where the drainage of the Cradle Valley and its southern tributaries was diverted from its preglacial course northeastwards along Smiths and Carruthers creeks to its postglacial course northwards through the Dove River gorge."

Colhoun proposed that the preglacial drainage ran approximately towards the northeast, parallel to the layering of the Precambrian rocks in the area (Fig. 5.28). The ice flowed across the pre-existing watershed between Hounslow Heath and Mount Kate. The strong glacial erosion of the Dove Gorge, coupled with thick glacial deposits across the head of Smiths Creek forced Ronny Creek and the streams draining Crater Lake and Lake Dove to discharge their water through the Dove Gorge.

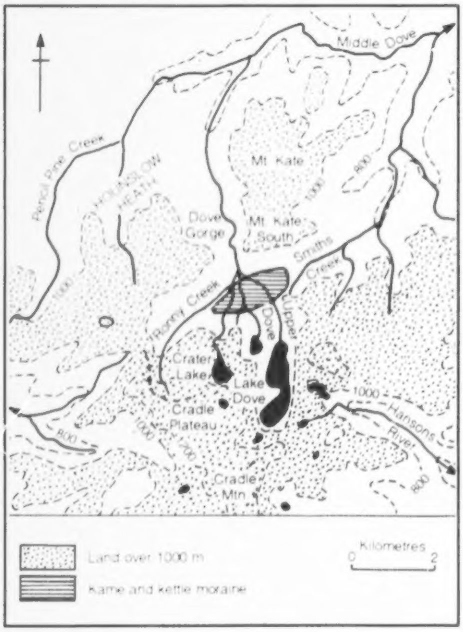

Middle Dove
Pencil Pine Creek
HOUNSLOW HEATH
Mt Kate
800
1000
Dove Gorge
Mt Kate South
Smiths Creek
Ronny Creek
Dove
Upper
Crater Lake
Lake Dove
Cradle Plateau
700
Hansons River
Cradle Mtn
Land over 1000 m
Kame and kettle moraine
Kilometres
0
2

Fig. 5.28c: Present drainage of the Cradle Mountain area.

Diversion of drainage by basalt flows

Eruptions and flows of volcanic basalt were common in the Tertiary in Tasmania. The basalt tended to flow towards and collect in the lowest parts in the area. This disrupted the flow of many Tasmanian rivers. Carey (1946) claims that the South Esk River used to flow northwards past Evandale, but that an outpouring of basalt near Evandale blocked this path and turned the South Esk River along its present course westwards to enter the Cataract Gorge at Hadspen.

Alwar (1960) detailed the diversion of the Derwent River in the Glenora area caused by basalt extrusions.

Nye in 1924 (in Banks 1962) used the location of alluvial tin deposits to map pre-basaltic drainage patterns in the North-East. The basalt displaced the Ringarooma River laterally (Fig. 5.29). Spry in 1958 (in Banks 1962) indicated that an ancestral stream, infilled by basalt, resulted in the formation of the twin streams of the Forth and Mersey Rivers (Fig. 5.29).

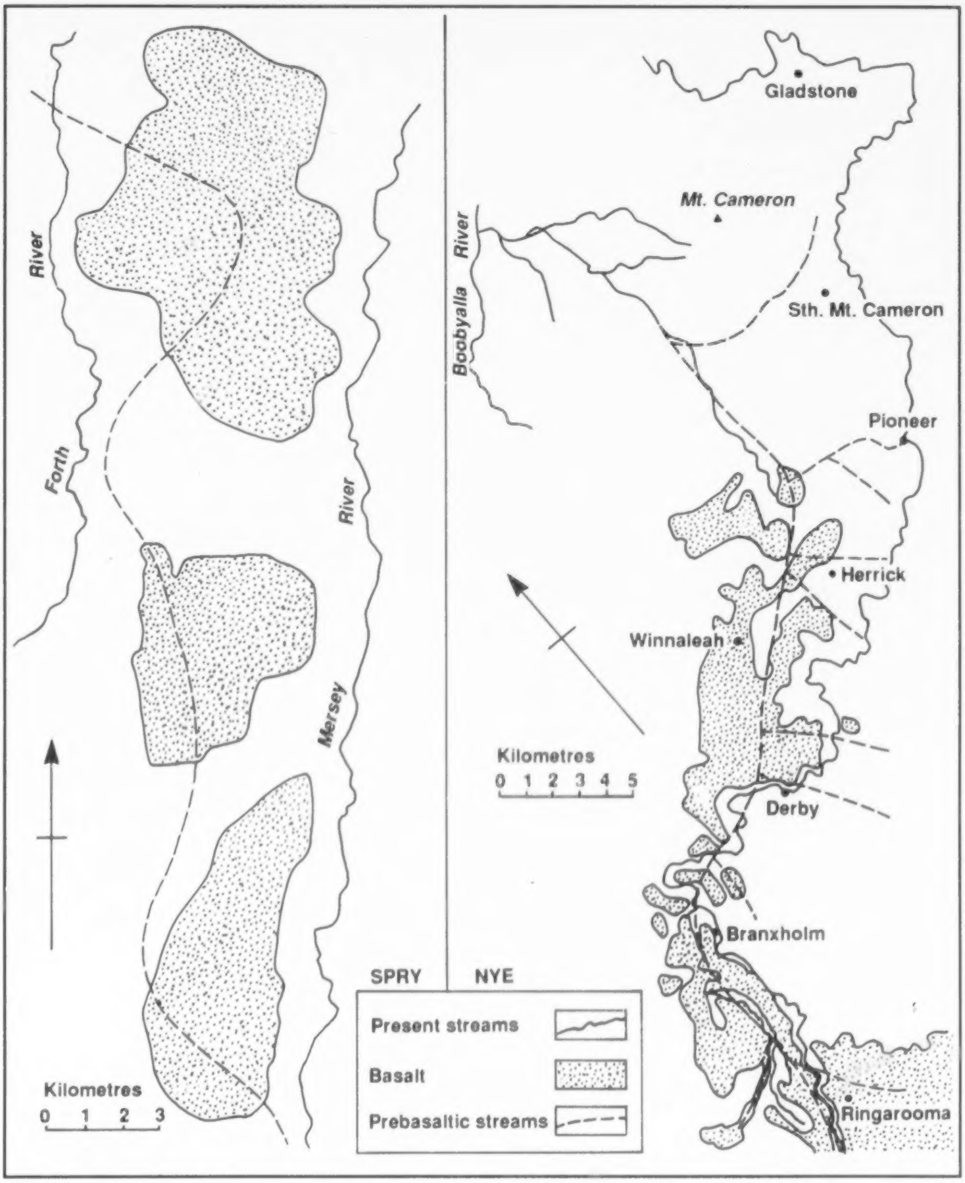

Forth River
Mersey River
Kilometres
0 1 2 3
SPRY
NYE
Gladstone
Mt. Cameron
Boobyalla River
Sth. Mt. Cameron
Pioneer
Herrick
Winnaleah
Derby
Branxholm
Ringarooma
Kilometres
0 1 2 3 4 5
Present streams
Basalt
Prebasaltic streams

Fig. 5.29: Diversion of rivers by basalt flows. (a) Mersey-Forth (b) Ringarooma River.

Diversion of drainage by human activities

Human activities have been responsible for large-scale changes to Tasmanian river systems. Dams have been built to provide water storages for a variety of purposes including irrigation, domestic water supplies and the generation of electricity.

The Hydro-Electric Commission has constructed a number of power developments in different parts of the State. Dams have created lakes on former river courses. Water flows have been diverted from one area to another.

- Water from the Derwent and Dee Rivers is diverted into the Nive River (a tributary of the Derwent).
- South-easterly flow from the Great Lake into the Shannon River is now sent north through the Poatina Power Station.
- Water from the upper catchment areas of the Mersey River is diverted at Parangana Dam. It flows in a westerly direction via tunnel and pipeline before passing through the Lemonthyme Power Station and into the Forth River.
- The Gordon Power Development involves the diversion of the upper reaches of the Huon River into the Gordon River.

River Systems in Tasmania

The major rivers in Tasmania can be divided into two categories:

- the **largely superimposed streams** flowing over folded Precambrian and Lower Palaeozoic rocks in the West and North-West (for example, the Gordon, King, Pieman and Mersey Rivers);
- the **largely graben-confined streams** flowing over near-horizontal Permian and Triassic sedimentary rocks and Jurassic dolerite in the Centre, East and South-East (for example, the Derwent and Tamar Rivers).

Largely superimposed streams

The Gordon-Franklin river system

The Gordon-Franklin river system is the largest catchment in western Tasmania. It is Tasmania's third largest system, being smaller than the South Esk and Derwent river systems. However in terms of yield the Gordon-Franklin catchment exceeds the yield of both the Derwent and South Esk systems combined. This is a direct result of the high annual rainfall figures for South-West Tasmania (Fig. 5.30).

The Gordon River rises from the glaciated flanks of the King William Range. Its largest tributaries, the Franklin and Denison rivers, also drain from glaciated country. The uppermost tributaries of the Gordon River are meltwater channels which drain from cirque lakes, the largest of these being Lake Richmond. **Moraines** extend out across the valley floor and small outwash plains are widespread.

A dramatic change of gradient occurs in the upper reaches of the Gordon River. In the Vale of Rasselas the Gordon meanders over outwash plains underlain by Ordovician limestone. Glacial sediments extend onto the valley floor from the Denison Range. The nature of the Gordon River changes dramatically as it swings towards the west and enters the steep sided Gordon Gorge upstream of the new artificial Lake Gordon.

Above its junction with the Serpentine River the Gordon is dammed and its path is now hidden below the waters of Lake Gordon, but here too it cuts through elevated ridges via steep gorges. The new Lake Pedder covers the interesting meandering path of what was the Serpentine River. This river drained the old Lake Pedder, a wide shallow depression dammed by outwash fans extending down from the cirques of the Frankland Range. The rapid change in gradient from the slow-flowing meandering Serpentine River to the actively down-cutting Gordon River in the vicinity of the Albert Rapids illustrates the stepped nature of this system.

This is characteristic of nearly all Tasmanian rivers. Gorge-like segments with steep gradients are found where rocks are resistant to weathering and erosion. Other segments with flat-floored valleys and gentle gradients occur where rocks are weak and easily

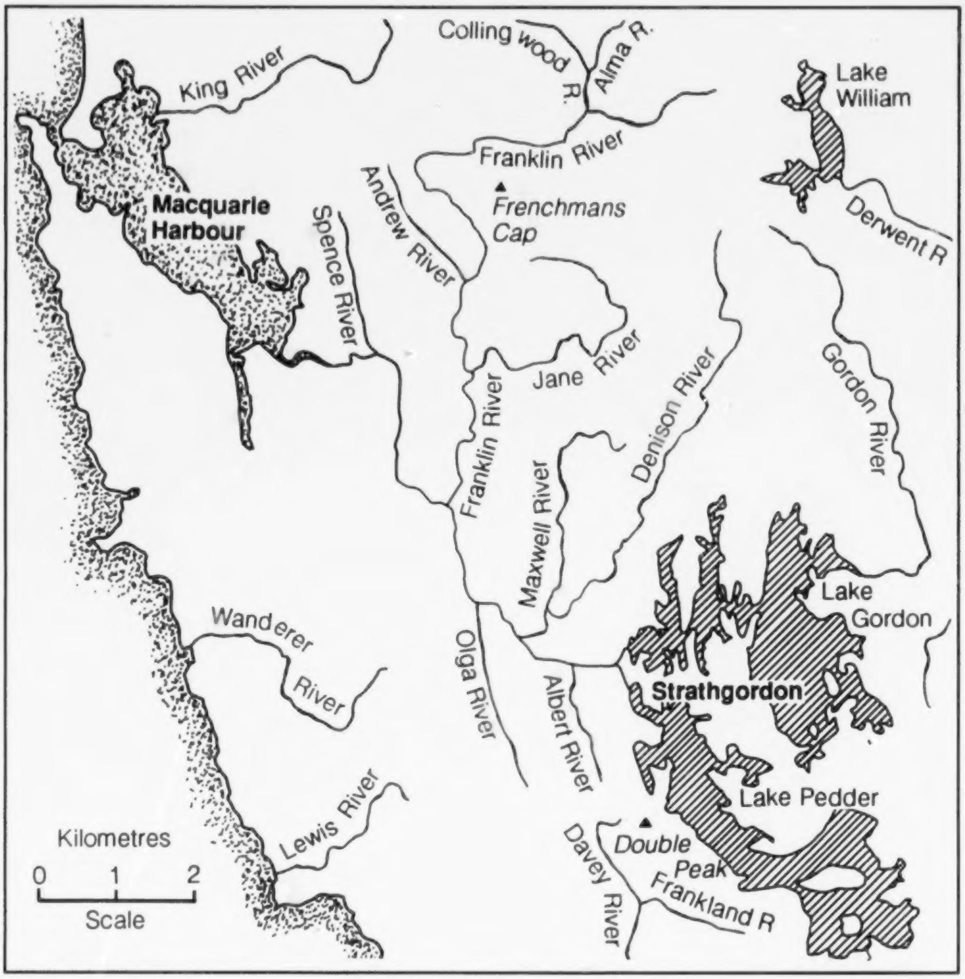

Colling wood R.
Alma R.
King River
Lake William
Franklin River
Andrew River
Frenchmans Cap
Macquarie Harbour
Spence River
Derwent R
Jane River
Franklin River
Denison River
Gordon River
Maxwell River
Lake Gordon
Wanderer River
Olga River
Albert River
Strathgordon
Lake Pedder
Lewis River
Double Peak
Davey River
Frankland R
Kilometres
0
1
2
Scale

Fig. 5.30: Gordon-Franklin System.

Fig. 5.31: Gordon River meandering over Vale of Rasselas then entering a steep sided gorge.

eroded. Many of the gorges may be due to superimposition from the courses of older streams flowing on a cover of flat-lying Permian and Triassic rocks.

The Franklin Valley has been glaciated on at least three and possibly four occasions. The Franklin River rises from the steep, glaciated slopes of the Cheyne Range. During the most intense glacial phase, ice from the Cuvier Valley spilled over **cols** at the head of the Franklin and Alma Valleys. Ice also arose in the Surprise Valley and in many tributaries of the upper Collingwood. The ice was at least 200 metres thick at the Collingwood-Franklin junction, and probably extended far enough downstream to join the north-flowing glaciers of Frenchmans Cap.

About 18,000 years ago, during the most recent glaciation, the ice extended down the Franklin Valley to Lake Dixon. Glacial meltwaters deepened the Franklin Gorge downstream of this point. This deepening also occurred in many of the tributary streams which drain the higher cirques. Extensive deposits of outwash gravel filled many of the valley floors during these cold glacial stages, and have been incised by the rivers during phases of warmer climate.

Fig. 5.32: First Gordon Split.

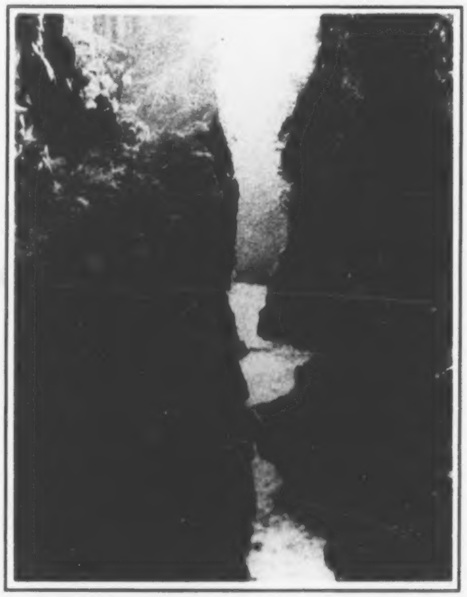


Fig. 5.33: Rafter.

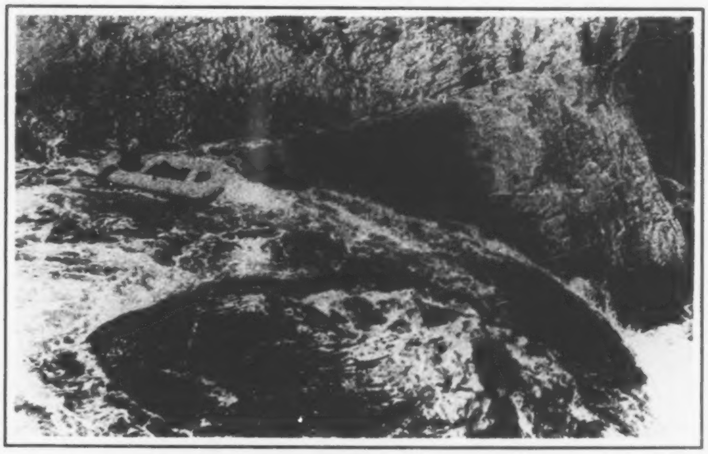
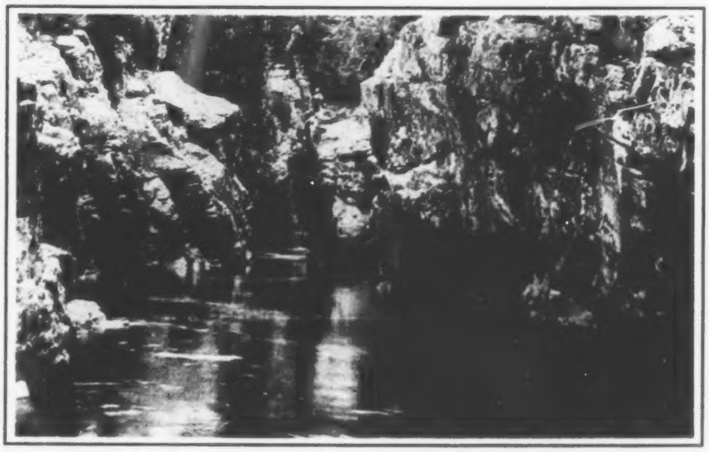


Fig. 5.34: Irenabyss.



The middle reaches of the Franklin north of its junction with the Nichols River is a typical but spectacular mountain tract course. It features massive gorges, rapids, deep pools and ravines as it skirts the northern and western margins of the Frenchmans Cap National Park.

Throughout this part of its course the river is actively **down-cutting,** and the influence of geology and structure on its course are much less apparent. The heavily glaciated Frenchmans Cap massif has contributed strong meltwater flows which have helped deepen the gorges. The low saddle at the head of the Andrew River has probably been breached by glaciers from the King River Valley which discharged meltwater and outwash gravel into the Franklin River system. North east of the Engineer Range the alignment of folds in the Precambrian rocks is predominantly northwest-southeast, and this has exerted some influence over the river direction. Here too the river is stepped, its gradient and direction changing sharply along its length, with substantial pools and basins separated by rapids and falls.

The generally trellised system of rivers in the catchment is exemplified in the lower Gordon-Franklin area. The pattern runs primarily north-south and is most apparent on the Olga River, the lower Franklin, and on the Gordon River downstream of its junction with the Orange River.

The trellis pattern in this region is due to the north-south trending system of anticlines and synclines which occur in the Precambrian and Palaeozoic rocks. This is best illustrated by the parallelism of the Olga and Orange rivers. The effect is further heightened by the alignment of the Olga, Gordon and Franklin Rivers. The Franklin flowing from the north converges on the Gordon flowing from the south, the predominant direction maintained by the Olga throughout its entire length.

This lower Gordon, lower Franklin pattern is further influenced by the presence of Ordovician limestones and calcareous siltstones. The valley of the Franklin River south of the eastern end of the Engineer Range passes from Precambrian metamorphic rocks to limestones and carbonate-rich sediments of Ordovician age.

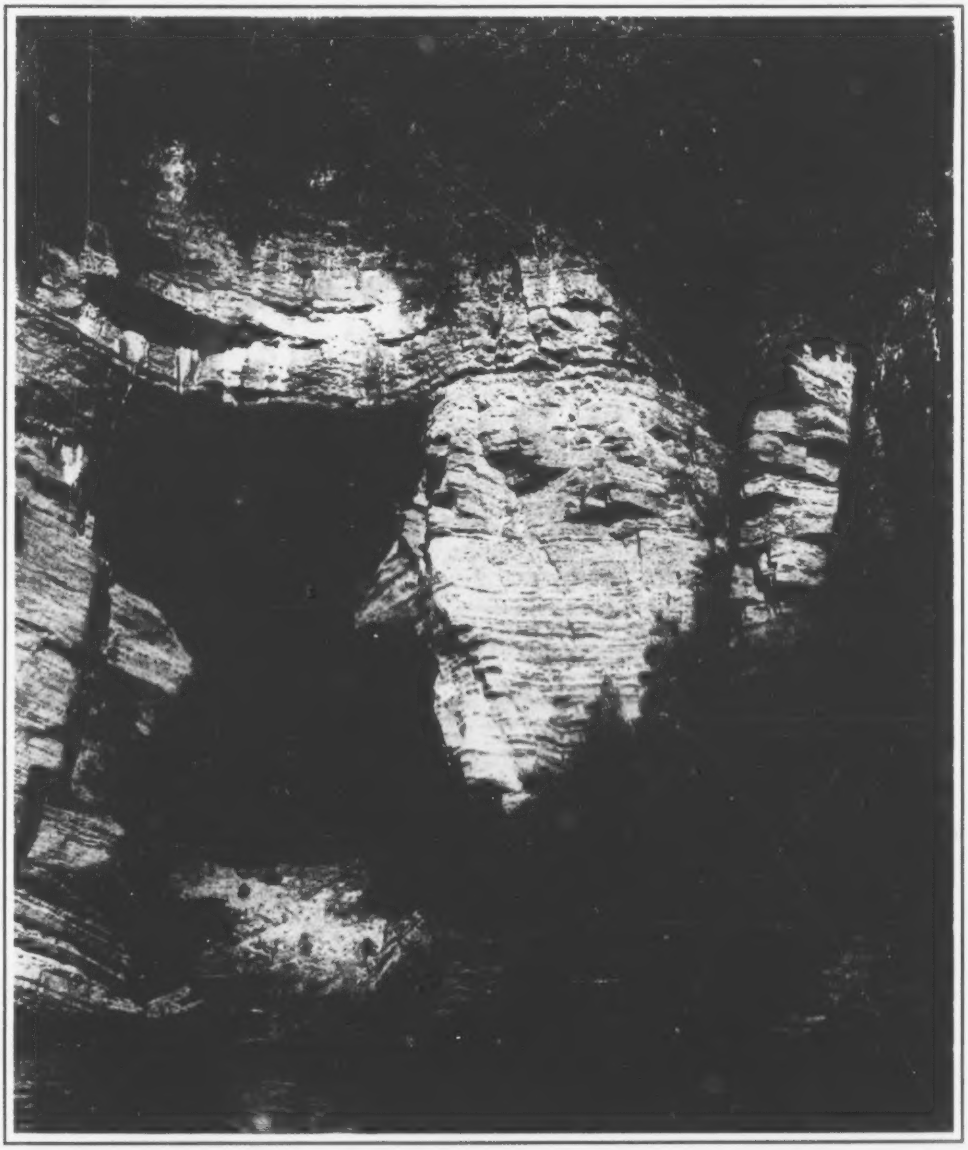


Fig. 5.35: Pengana Arch, the largest and most impressive cave entrance of the Franklin River Caves.

These sediments strike north-south and confine the Olga, Gordon and Franklin Rivers to that direction over a distance of some 30 kilometres. The influence of this limestone is also apparent further down the Gordon River where after flowing westerly it veers sharply northward about 10 kilometres below its junction with the Franklin. It continues on this northerly course until near its junction with the Spence River. For this entire stretch the river is almost confined to the limestone, apart from some unconsolidated sediments.

Largely graben-confined streams

Tamar River System

The Tamar river system includes a number of streams such as the South Esk, the North Esk, the Meander, the Macquarie and the St Patricks. The South Esk is the major stream, and from an historical point of view the system is really the South Esk system with the North-Esk as one of the major tributaries. The Tamar River is the drowned valley or estuary of the system. The present day system has a drainage basin covering some 18% of Tasmania's land surface.

The Tamar River, in a similar fashion to some other major rivers, was initiated in early Tertiary times by a major period of faulting which resulted in the formation of extensive lowland area.

While the Western Tiers and Ben Lomond Highlands were probably uplifted by the same generation of northwest-trending normal faults, lakes formed in the lowland area. Lake Cressy, some 80 kilometres long and 12 to 25 kilometres wide, extended from Frankford and Deloraine to Campbell Town. Lake Tamar, further east, was almost as long but somewhat narrower. Large quantities of sediments were washed into these lakes in early Tertiary times, while the two major lakes eventually combined to form one lake, Lake Launceston.

Two periods of volcanic activity are found in the Tamar Valley. These enable a three-fold classification of sediments:

- The **pre-volcanic sediments** include clays, sands and gravel and boulders. They increase in thickness to the south, being over 800 metres thick in the Cressy-Longford area. They do contain plant impressions but they are usually quite unconsolidated and weather readily, making outcrops rare.

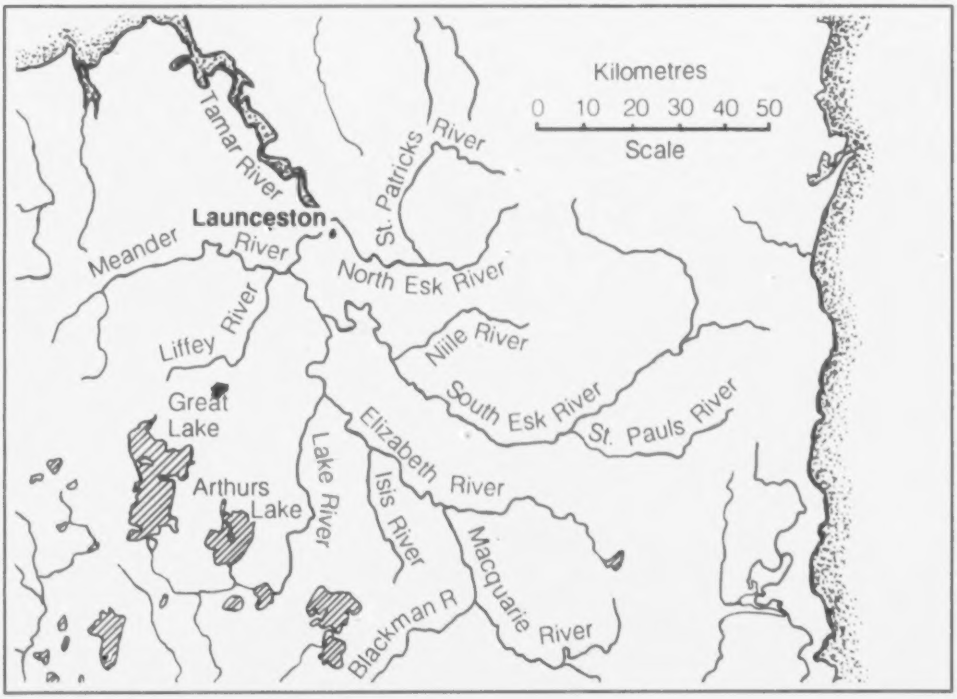

Kilometres
0 10 20 30 40 50
Scale
Tamar River
St. Patricks River
Launceston
Meander River
North Esk River
Liffey River
Nile River
South Esk River
St. Pauls River
Great Lake
Arthurs Lake
Lake River
Elizabeth River
Isis River
Macquarie River
Blackman R

Fig. 5.36: Locality sketch of the Tamar River System.

- Clays, sands and boulder beds of the **intervolcanic sediments** are found in the middle and lower Tamar. The boulder beds are well known from a number of locations and are found to contain fragments of the older basalt while being overlain by the younger ones. The boulder beds of these Miocene units comprise dolerite boulders up to 40 centimetres in diameter. These boulder beds are located near major faults.

- The **post-volcanic sediments** vary from quartz sands and gravels in the lower Tamar to basaltic gravels and laterites between St Leonards and Evandale.

The eruption of the Miocene basalts terminated the original stage of sedimentation in Lake Launceston. The lava extruded from many small fissures which appear to have a common direction with the earlier fault zones. The lava flowed down onto the valley floor. These flows were to have a major influence on the river courses.

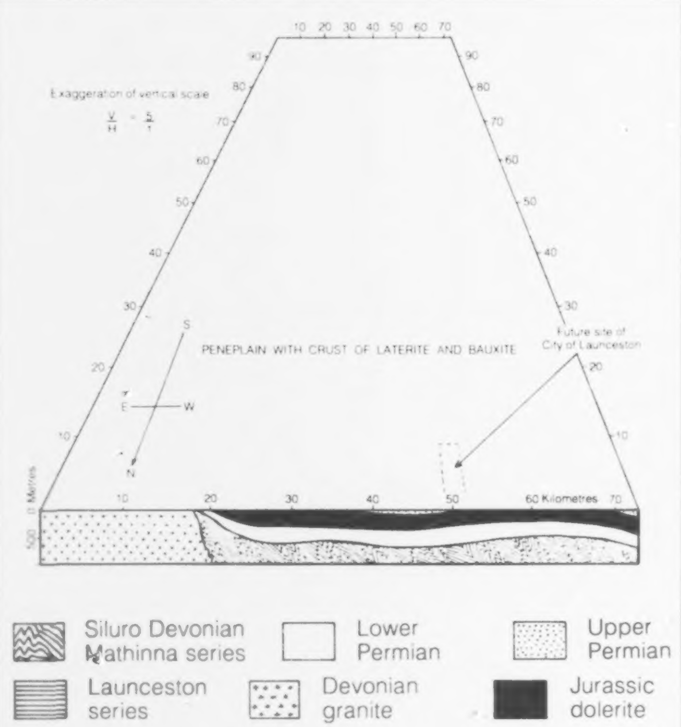
In the middle Tamar, near Whirlpool Reach, basalts dammed the river and established a new lake, while further upstream other flows altered the course of the South Esk. It appears that before the volcanism the South Esk flowed in a straight valley from near Campbell Town through Evandale to St Leonards, while the Macquarie flowed northwards to the west of the Hummocky Hills Horst.

Basalts in the Evandale area dammed the South Esk and diverted it to its present course through Longford and Hadspen, joining the Macquarie near Longford.

A third possible diversion of the system due to lava may have been in the Lower Tamar with the river being pushed west of its previous channel to flow through Beaconsfield and out between Badger Head to West Head. This would explain the extensive upper Tertiary sediments in that area.

While the barrier existed at Whirlpool Reach, the South Esk and North Esk met in a lake about 200 metres above their present junction. In this lake were deposited the sands, clays and occasional gravels on which present-day Launceston stands. The North Esk, flowing entirely in the soft Tertiary sediments, easily maintained its direction by vertical and headward erosion. The South Esk, flowing in many places over horizontal

Fig. 5.37 a: The early Tertiary peneplain.


Exaggeration of vertical scale
V/H = 5/1
PENEPLAIN WITH CRUST OF LATERITE AND BAUXITE
Future site of City of Launceston
S
E
W
N
10
20
30
40
50
60
70
80
90
60 Kilometres
500
0 Metres
Siluro Devonian Mathinna series
Lower Permian
Upper Permian
Launceston series
Devonian granite
Jurassic dolerite

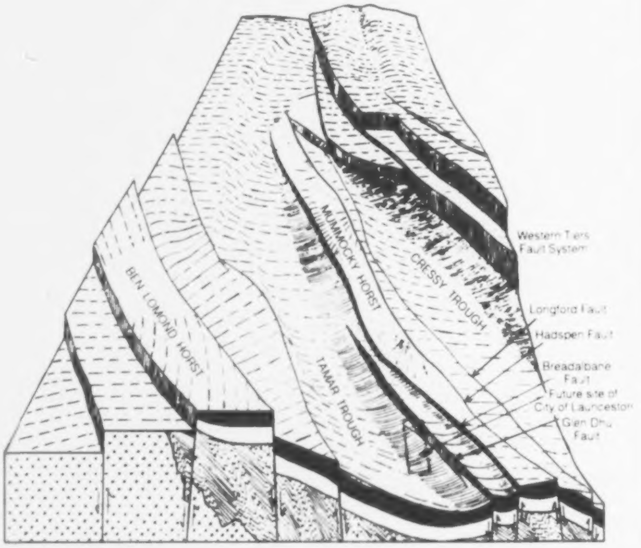
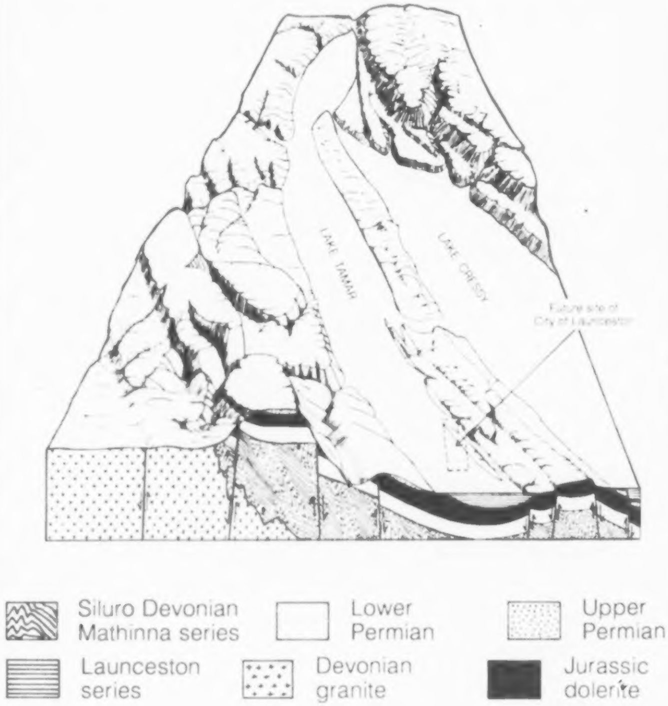

BEN LOMOND HORST
HUMMOCKY HORST
CRESSY TROUGH
TAMAR TROUGH
Western Tiers Fault System
Longford Fault
Hadspen Fault
Breadalbane Fault
Future site of City of Launceston
Glen Dhu Fault

Fig. 5.37 b: The same area immediately after the faulting.

Fig. 5.37 c: The lakes showing rapid dissection of the new mountains, filling up the depressions with gravels, sands, and clays to a thickness of over three hundred metres.


LAKE TAMAR
LAKE CRESSY
Future site of City of Launceston
▨ Siluro Devonian Mathinna series
☐ Lower Permian
▨ Upper Permian
▤ Launceston series
▨ Devonian granite
■ Jurassic dolerite

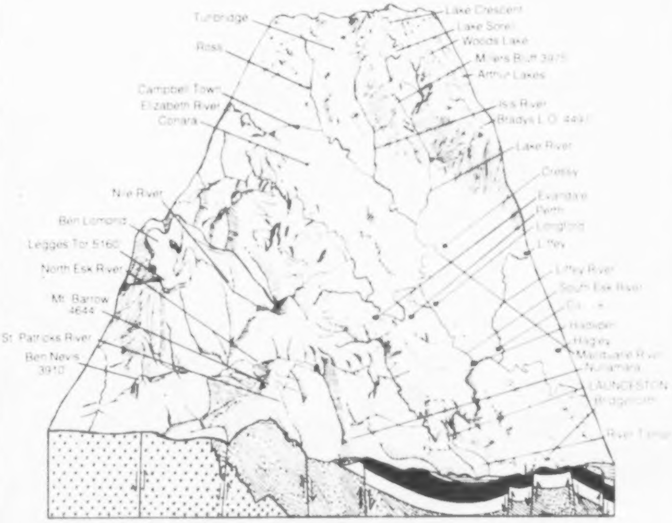

Tunbridge
Ross
Campbell Town
Elizabeth River
Conara
Nile River
Ben Lomond
Legges Tor 5160
North Esk River
Mt. Barrow 4644
St. Patricks River
Ben Nevis 3910
Lake Crescent
Lake Sorell
Woods Lake
Millers Bluff 3975
Arthur Lakes
Isis River
Bradys L.O. 4491
Lake River
Cressy
Evandale
Perth
Longford
Liffey
Liffey River
South Esk River
Hadspen
Hagley
Macquarie River
Nunamara
LAUNCESTON
Bridgenorth
River Tamar

Fig. 5.37 d: The present-day, after diversion of the Upper North Esk River into the South Esk by basalt flows near Evandale and the scouring out of the Tertiary sediments from the Tamar Valley.

sheets of resistant dolerite, deepened its valley without widening it, and entrenched itself to form the beginnings of the Cataract Gorge.

When the river finally broke through the barrier at Whirlpool Reach, rapid erosion of the valley took place. This down-cutting was particularly active during periods of very low sea level, during the ice ages, which was when the Gorge was excavated to its present form.

During the melting stages of the last Pleistocene glaciation the Tamar system carried a great deal more water that it does today. This resulted in the formation of large valleys which today are misfit features, particularly in the Fingal Valley.

About **9,000 years ago** sea level rose several metres above its present level. As a result, St Leonards was put in the tidal zone. Widespread tidal flats were formed in that area of the North Esk valley. Later they were left deserted when sea level dropped to its present height.

Of special interest in the area is the impending river capture of the South Esk by tributaries of the North Esk near Evandale. In this area the level of the South Esk is controlled by a dolerite bar near Hadspen, at an altitude of 135 metres. Three kilometres to the east of Hadspen, Rose Rivulet, a tributary of the North Esk, is at an altitude of 45 metres. The divide, consisting of a thin basalt cap on soft Tertiary sediments, is only 15 metres above the present low water level in the South Esk. Future capture at this point would divert most of the present South Esk flow down the North Esk.

Unsightly mud flats are situated at the head of the Tamar estuary. Silt from the South Esk and North Esk catchment areas is redistributed by tidal movements. Pollution of the estuary compounds the problem.

Derwent River System

The Derwent River has its source at the southern end of Lake St Clair. The river drains the greater portion of the Central Plateau, and enters Storm Bay through its flooded lower valley which we refer to as an estuary (see figure 5.38).

It is a large river which owes its scenic beauty to three causes — faulting in the early Tertiary Period about 65 million years ago, glaciation during the Pleistocene, and the drowning of the lower valley due to a rise in sea level after melting of the Pleistocene ice sheets between 18,000 and 6,000 years ago.

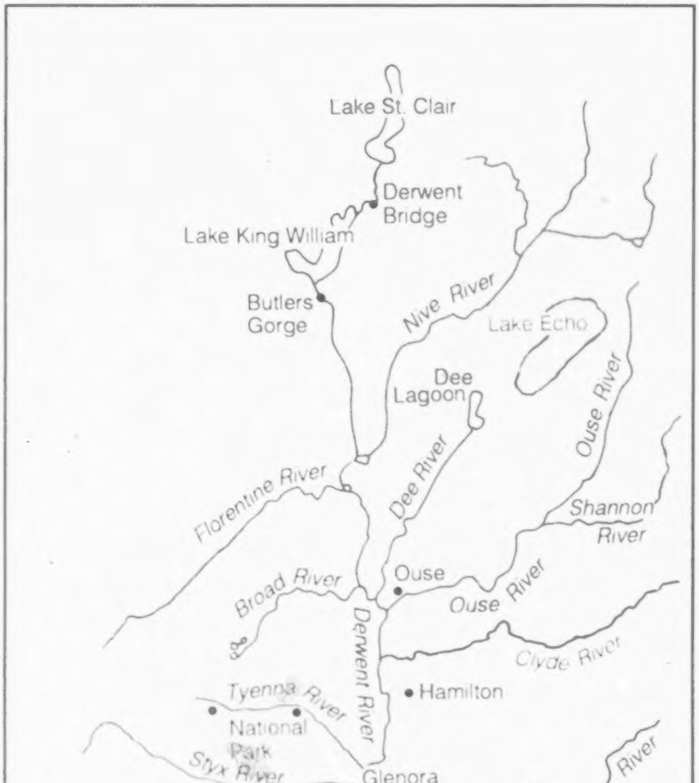
The Derwent River rises from Lake St Clair, an over-deepened glacial trough blocked at its downstream end by a complex of end moraines. The upper Derwent Valley has probably been glaciated on at least three occasions. The maximum limit of the area affected by glaciation has not yet been established, but glacier ice has extended beyond Butlers Gorge on at least two occasions (Kiernan 1983).

The Derwent River probably originally exploited a fault between the Traveller Range and Mount Olympus, with glacial erosion and deposition later guided by the preglacial topography.

Today Lake St Clair is fed by streams which drain a series of tributary glacial troughs. The largest of these is the Narcissus trough which originates in a three-kilometre wide composite valley-head cirque on the southern side of the Du Cane Range. This valley-head cirque is located between Du Cane Gap and the Acropolis.

Further downstream the western part of the central plateau has been severely eroded by ice moving into the St Clair trough past Mount Ida, where it greatly deepened the valley floor. South of Mount Olympus and the Traveller Range, the glacier spread out as a piedmont lobe. The surface of the glacier declined eastwards, and the lower pressures beneath the thinner ice on the eastern margin encouraged subglacial meltwater flow to be concentrated there. This led to the development of the short rock-cut gorge between Mount Charles and Bedlam Walls through which the river now flows. The original course, probably between Mount Rufus and Bedlam Walls, has been blocked by recessional end moraines.

Fig. 5.38: Locality map of Derwent River System.


Lake St. Clair
Derwent Bridge
Lake King William
Butlers Gorge
Nive River
Lake Echo
Dee Lagoon
Ouse River
Florentine River
Dee River
Shannon River
Broad River
Ouse
Ouse River
Derwent River
Clyde River
Hamilton
Tyenna River
National Park
Styx River
Glenora
Gretna
Bushy Park
Macquarie Plains
Jordan River
Plenty
Moogara
New Norfolk
Bridgewater
N
Claremont
Cornelian Bay
Hobart
Sandy Bay
Huon River
D'Entrecasteaux Channel
Nth. Bruny Island
Sth. Bruny Island
Storm Bay
Kilometres
0 10 20
Scale

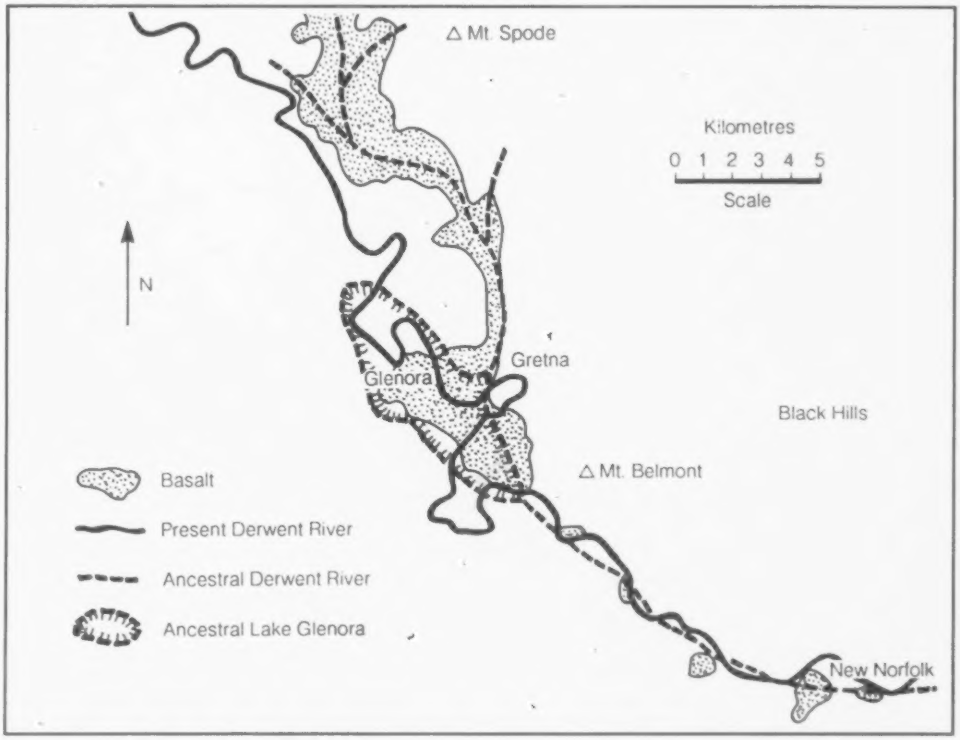


Fig. 5.39: Drainage of the Derwent River before and after basalt extrusions in the Glenora area.

During the most recent glaciations about **18,000 years ago** the ice extended to just south of Lake St Clair. On at least two earlier occasions glaciers extended beyond Butlers Gorge, which has been considerably deepened by eroding glacial meltwater. Seasonal, torrential meltwater flows carried a considerable quantity of outwash gravel down the Derwent river system. At Butlers Gorge the course of the river changes abruptly to flow in an east by north east direction, along the southern margin of an outwash plain before resuming its south-easterly trend in a structurally controlled valley incised in dolerite.

A considerable quantity of glacial outwash gravels also reached the Derwent via the Nive River. Between the Nive and the Florentine River tributaries, the structural control of the Derwent is evident. The Derwent is controlled by a fault system running north-northwest. Further outwash gravels from the Mount Field area entered the Derwent Valley from the Florentine.

The lower part of the Derwent was initiated as a series of lakes along the floor of the down-faulted trough in which were deposited clays, sands and gravels. The basalts which were extruded later in the Tertiary Period modified the course of the Derwent. The river has now cut into the underlying Triassic sedimentary rock and the Jurassic dolerite. The heavily glaciated Broad River Valley discharged a further supply of outwash gravels into the Derwent where they form substantial terraces.

The Derwent Valley, in the region of its confluence with the Tyenna and Styx Rivers, is controlled by early Tertiary faulting which initiated the Derwent Graben. Resistant dolerite is also partially responsible for keeping the river within the graben, both before and after the basalt flows — which occurred at some time during the Tertiary Period. The floor of the early Tertiary graben was uneven at first, with lakes in the low lying areas. Among the largest of these lakes was the ancestral Lake Glenora (figure 5.39), which extended from Meadowbank Road to Plenty in a southeasterly direction and from Clarendon Homestead to the present Styx River in a north-south direction. The ancestral Derwent then flowed through these low lying areas and lakes, connecting them through a series of cascades and rapids. Then successive filling of the lakes and valley by Tertiary basalt dislocated the drainage system.

The new courses tended to be along either side of the basalt as lateral streams. The diversion of the Derwent took place beyond Ouse and it flows on the south-west side of the basalt as a lateral stream until it reaches the Kenmore basalt tableland. Here it was forced to cut a channel through the basalt. Incised meanders are present in the valley of the Derwent in this region.

The Styx River once flowed in to Lake Glenora, but it was diverted to flow as a lateral stream between the basalts and the Moogara Plateau. The valley of the Styx around Bushy Park and Macquarie Plains is wide and flat and the course of the river is very meandering, at least one ox-bow lake or billabong being present. Five terraces, including one at two to three metres above stream level and another at six metres above the first, were probably due to reductions in base level or to climatic change.

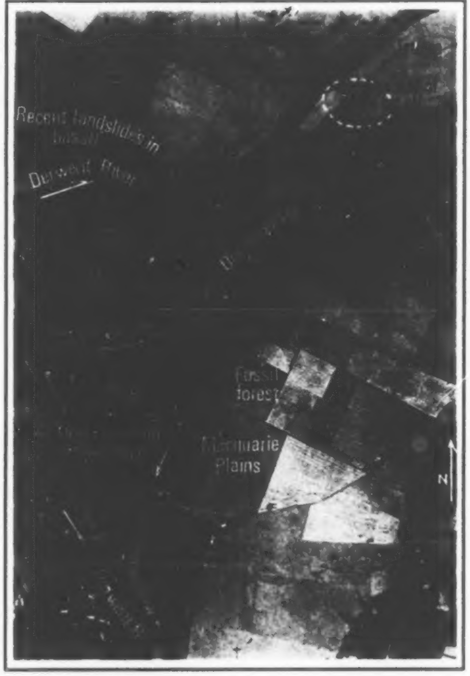
Because the Derwent's meanders will enlarge in the future, the river is likely to cut through the narrow divide just north-northeast of Bushy Park to join the Styx, leaving several kilometres of the Derwent course as a large ox-bow lagoon.

The wide valley of the Derwent upstream from New Norfolk is again a low lying area between two upthrown fault blocks. The Derwent River at New Norfolk flows through a zone where the river has alternated between phases of deposition and phases of downcutting. These alterations are a result of the repeated changes in climate and sea-level during the Pleistocene. As a result, a sequence of alluvial terraces has developed on which the town of New Norfolk has been built.

The extrusion of Tertiary basalt at New Norfolk itself probably diverted the river out of the down-faulted block and here it flows in a north-easterly direction. However, the structural control is again evident a little downstream from the township of New Norfolk.

Upstream from Bridgewater, the Derwent is slowed by friction due to the effects of the tide. As a result, the competence decreases and much of the suspended load is dropped. The finer material is flocculated by the saline tidal water, and the resulting deposit is an estuarine delta. The Derwent west of Granton is kept in its channel by a low natural levee upon which a distinctive type of shrub seems to thrive. Between this levee bank and the Lyell Highway there is a marshy flood plain deposit. In the Claremont-Austin's Ferry region the Derwent crosses the softer sediments on the down-faulted side of a large fault. Again emphasis must be placed on the structural control of the river. The coarse gravels which form the terraces adjacent to this reach of the river, are covered in places by fine sands which were blown from the braided bed of the Derwent when the sea was below its present level during the last glaciation.

Fig. 5.40: An incised·meander of the Derwent River near Macquarie Plains.



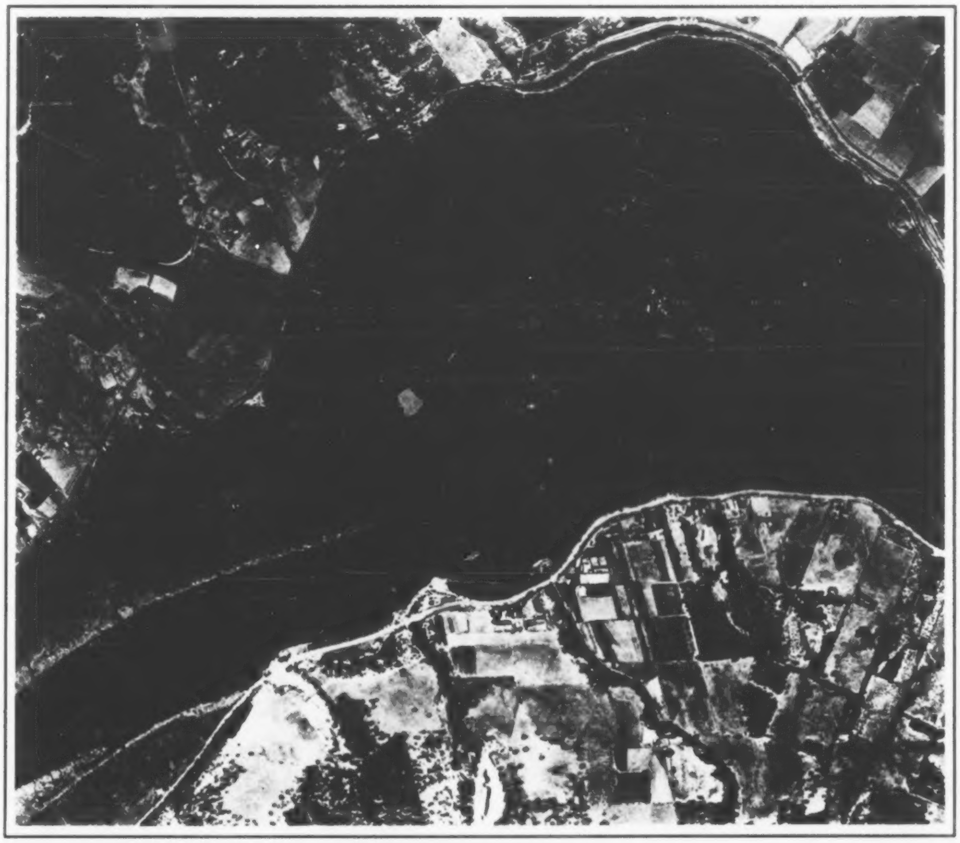
The Jordan River enters the Derwent at Herdsman's Cove. It has cut its course through basalt which probably dammed the Jordan in the Tertiary Period.

The Derwent Valley in the Cornelian Bay-Sandy Bay area shows evidence of being initiated as a graben bounded by a complex system of intersecting faults. Firstly, lakes were formed in the downthrown blocks, Tertiary sediments being deposited in them. Further tension resulted in repeated movements along some of these faults, and magma rose along major fractures. A number of volcanic cones which must have been situated in the Derwent estuary (near Self's Point and Blinking Billy Point) have been worn away by subaerial erosion.

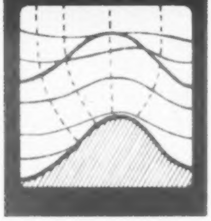
The physiography of the Derwent south of Hobart is to a marked degree controlled by the drowning of the estuary since the Pleistocene Epoch. As a result, the banks of the Derwent are extremely irregular. Hills in existence before the post-glacial increase in sea level are now headlands, and the small tributary valleys are now indentations in the coastline. Spits and tie barriers have been formed due to shore drift along the indented coast. Eventually erosion and deposition will probably smooth out all the intricate outlines of this type of shoreline. D'Entrecasteaux Channel represents the flooded portions of either the Derwent River or morelikely, of tributaries of the Derwent and Huon Rivers. The 'islands' now joined to the mainland or to one another, such as those of South Arm and Bruny Island, were also formed by post-glacial submergence.

1946.

Fig 5.41: Two aerial photos showing growth in the estuarine delta of the Derwent (1946-1981) upstream from Bridgewater.



1981



Chapter six

Waves and coastlines

Ron Bugg

Introduction

Much of Tasmania's scenic beauty consists of coastline features — the rugged grandeur of the southern and south-eastern coastline; the drowned estuaries so prevalent around the island; erosional features such as Tasman Arch, the Blowhole, Remarkable Cave and the numerous stacks on Tasman Peninsula; and the beaches to which people flock during the summer months.

The energy of the waves

The sculpturing of our coastline is mainly the work of waves; shore currents have little influence.

Waves are caused by the wind. The wind sets up forces which cause water particles to move in an orbital fashion (see figure 6.1b). Water particles move forward as they ride the crest of a passing wave, downward as they ride down the back slope, backward in the trough and upward on the slope of the following wave. Contrary to what appears to be the case, it is the wave form which progresses — not the water particles themselves. The energy imparted to the water by the wind is carried by the waves in the form of swell.

The significant features and dimensions of waves in deep water are shown in diagram (Fig. 6.1a). The vertical distance between crest and trough is termed the **wave height** (H), the horizontal distance between successive crests or troughs the **wave length** (L), and the rate of travel of the waves is the **wave velocity** (V).

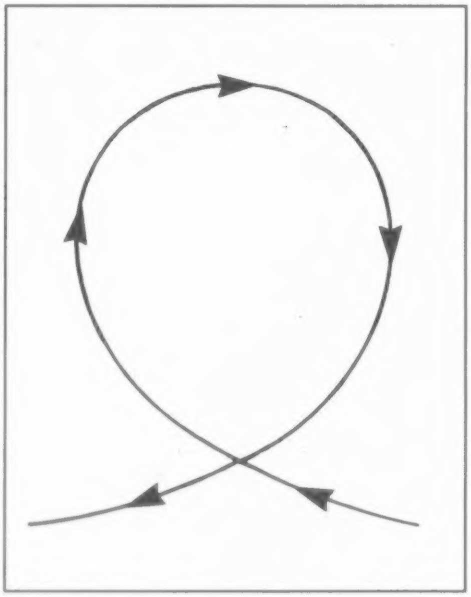


Fig. 6.1b: The path of a water particle during the passage of a single wave.

Waves receive their energy from winds at the surface, and are created by the orbital motion of the water particles. At depths greater than half a wave length there is virtually no movement of the water particles at all. Thus at these depths wave action is negligible. In water less than this critical depth, motion at the bottom becomes great enough to move fine rock particles to and fro.

As soon as a wave 'touches bottom' the orbit of the water particles changes from a circle to an ellipse. The waves increase in height, decrease in velocity, and decrease in length. Eventually, at a depth approximately equal to the deep-water wave height, the **plunge point** is reached and the wave breaks (see figure 6.2).

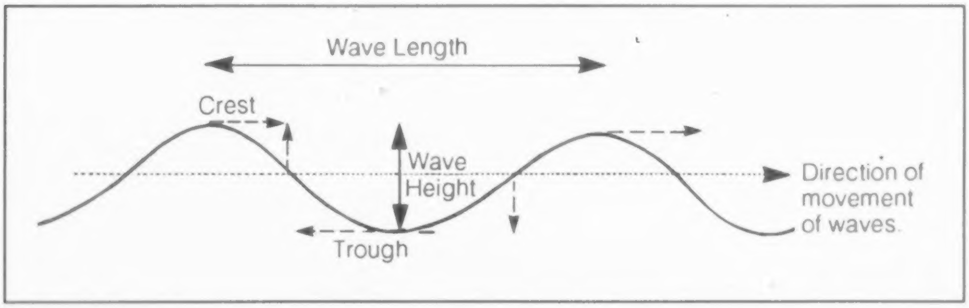
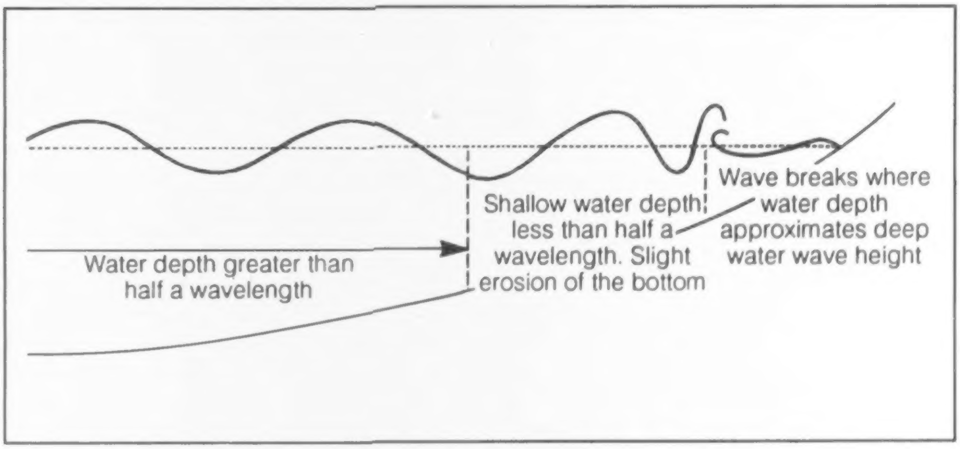


Fig. 6.1a: The direction of movement of particles at the surface of a water wave. The diagram also shows the characteristics of waves in deep water.

Fig. 6.2: Waves become higher and shorter as they move towards the shore. The wave first 'feels bottom' at a depth equal to half wavelength. At depths less than this changes in wave form occur and slight erosion of the bottom occurs. At a depth approximating deep water wave height, the wave breaks. Between plunge point and the shore most of the wave energy is dissipated.


Wave breaks where water depth approximates deep water wave height
Shallow water depth less than half a wavelength. Slight erosion of the bottom
Water depth greater than half a wavelength

At the plunge point energy dissipation is great, and what little is left is further expended in the trip to the shore, the energy becoming zero at the limit of uprush to the shore. Thus most of the geological work of waves on coastlines is accomplished by the surf between plunge point and the shore. The water piled against the shore flows directly down the slope under the influence of gravity. This has an important bearing on the process of the **longshore drift**.

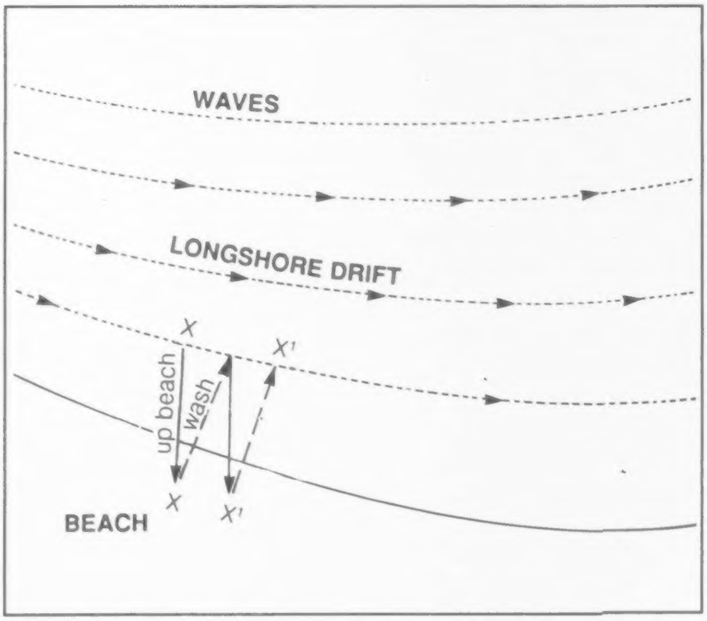

WAVES
LONGSHORE DRIFT
X
X¹
up beach
wash
X
X¹
BEACH

Fig. 6.3: Longshore drift.

Longshore drift

When waves are oblique (at an angle) to the coastline, a process known as a longshore drift is set up. Longshore drift transports material along a shore. Due to the dominant oblique direction of waves material is carried obliquely up the beach and then moved straight down the beach by backwash. This action carries material sideways.

Look carefully at figure 6.3. A particle at point **X** is carried into the shore by a wave. This water will then move outward under the influence of gravity, roughly at right angles to the shore. The particle is now in position **X^1**. From **X^1** the particle is picked up by the next wave and the process is repeated.

Longshore drift creates a tendency for headlands to be worn back and bays to be infilled. This causes the coastline to be straightened. Longshore drift plays an important role in distributing sediment and is the factor controlling the almost endless process of beach drifting. This important phenomenon is also the dominating influence in the formation of **bay mouth spits** and **mid-bay spits** as well as **bayhead beaches**.

Wave refraction and shoreline features

General

A number of important facts have very much simplified the study of shoreline development in southern Tasmania. These may be listed as follows:

- the drowned, deeply indented coastline;
- the fact that virtually the whole of the inner continental shelf and beaches are composed dominantly of sand-size material;
- the maximum tidal range of 0.9 to 1.2 metres;
- the fact that there is only one high tide a day.

It might be noted that Tasmania's Bass Strait coast has significantly bigger tides which often occur twice a day.

Origin of shoreline curves

Wave action has an decisive influence on the shape of the shoreline. **Wave direction** is a most important factor in any assessment of wave action. Anyone who has seen aerial photographs of waves approaching relatively enclosed beaches or who has stood on a rise overlooking such a beach, has probably observed that the approaching wave fronts parallel not only the general **plan** of the beach, but reproduce also any minor deflections in the profile of the beach (see figure 6.5).

The direction of the dominant swell, rather than the occasional storms, is of greater importance in the construction and alignment of sand beaches. In waters where the depth is less than half a wavelength, the wave fronts of the swell adjust to the underwater contours. In turn, the beaches are easily modifed to conform with the wave direction. In contrast, rocky coastlines don't adjust to conform to wave direction.

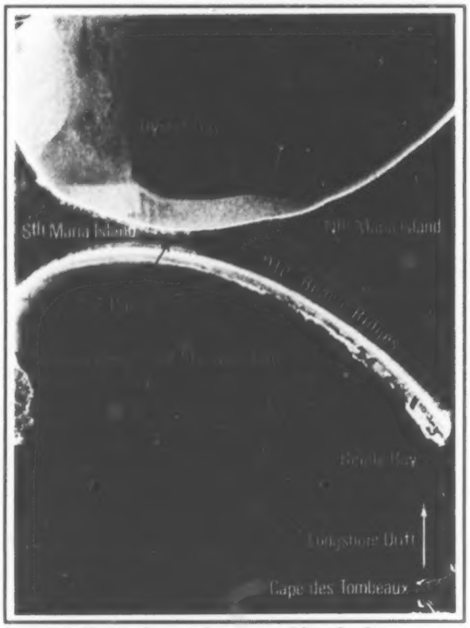

Sth Maria Island
Nth Maria Island
Longshore Drift
Cape des Tombeaux

Fig. 6.4: Coincidence of wave and beach plans along the tie barrier between North and South Maria Islands.

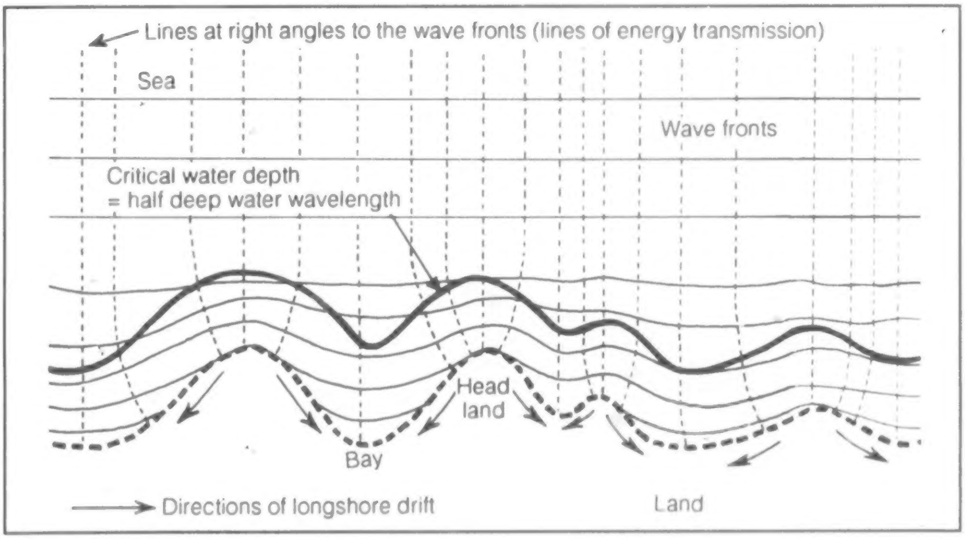

Lines at right angles to the wave fronts (lines of energy transmission)
Sea
Wave fronts
Critical water depth
= half deep water wavelength
Head
land
Bay
Directions of longshore drift
Land

Fig. 6.5: Refraction (bending) of waves does not occur until the approximate depth of half the deep water wavelength. The beach plan parallels the wave plan. Longshore drift moves material from the headlands towards the bays and thus the coastline tends to be straightened.

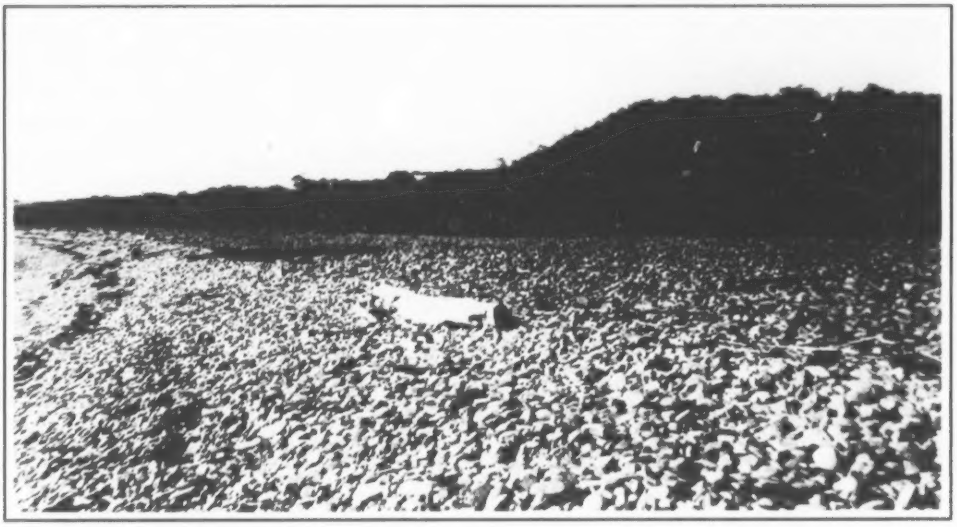


Fig. 6.6: Lillico's Beach (North-western Tasmania). This is an extensive shingle beach, which is uncommon in Tasmania. The slope from the berm to the sea is much steeper than for sand beaches.

The relative importance of storm waves and swell

It has often been maintained that storm waves are the dominant beach builders for all grades of material — but the action of storm waves upon sand beaches differs quite considerably from their action on shingle beaches.

With **shingle beaches**, the excessive backwash associated with storm waves is not so important because much of the backwash percolates through the shingle. Thus little erosion or cutting of the beach takes place. Indeed shingle beaches may well be built up as the storm's energy throws material up above the high water mark to form a high ridge.

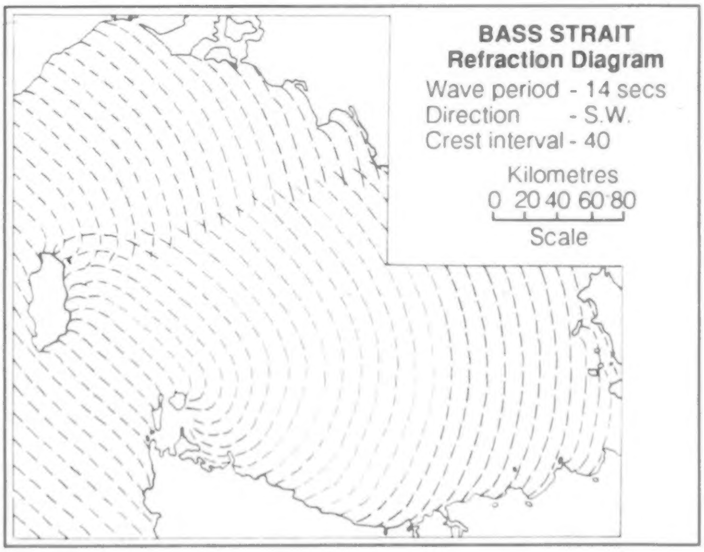


Fig. 6.7: Refraction diagram for a 14-second swell entering Bass Strait from the south-west. The northern beaches are an expression of the south-westerly swell.

However, during the action of storm waves on **sand beaches**, much of the material is placed in suspension by backwash, thus making its seaward- removal considerably more effective. A comparison of summer and winter profiles bears this out. Erosion of the beach occurs during storm wave action, while normal swell repairs the damage.

Shingle beaches are not particularly common on Tasmania's coast, but Lillico's Beach near Devonport is a well-known example.

Sand beaches may be constructed and extended above high water mark when a **berm** has been formed. Berms are wave-built features that resemble small terraces with low ridges on their seaward edges. Berms are formed by the action of the dominant swell. Windblown sand accumulates on the berm and the beach is extended above the high water mark. Seaward from the berms to low tide is the foreshore. Inland from the shore lies the coast.

In Tasmania, a long, low, south-westerly swell with a period of between twelve and fifteen seconds is constantly reported by recording stations on the West and Southwest coasts. This swell breaks unceasingly on beaches along these coasts. It is this swell, which can be observed to arrive parallel with the beaches, which builds lines of **beach cusps** (uniformly spaced ridges) all along such beaches. The action of this dominant swell also constructs a continuous beach berm upon which embryonic dune ridges arise. Thus the whole beach regime is an expression of this particular set of waves (Fig. 6.7).

The south-westerly swell entering Bass Strait is split into two 'sections' by King Island. The northern section influences the alignment and plan-form of beaches on the Victorian coast. The southern section influences beaches on the Tasmanian coast.

Impact of storms

Occasional storms seem to act as interruptions to this system. They destroy the beach cusps and berms, cut away the embryonic dunes and sometimes erode the older foredunes behind. The storms upset the regular curve of the beaches, and some may be temporarily straightened out (Fig. 6.8). After the storm waves have died down, the dominant swell, south-westerly in the case of Tasmania, again takes control and restores the normal character of the beach (Fig. 6.9).

Wave refraction and erosion features

Wave refraction often seems to be directly responsible for such minor erosional features as arches, stacks and some small sea caves. It is also thought that wave refraction results in the more rapid erosion of a headland when compared with a bay. This results in the sea having a tendency to straighten its shoreline.

Figure 6.4 shows why erosion is focussed to a large degree on headlands. The wave front in the vicinity of the headland tends to curve around, because of refraction in the shallow water. This bending of the wave front will not take place until the sea bottom has shallowed to the depth of about half a wavelength. With normal swell on the Tasmanian coastline this occurs at a depth of about 6 metres. In all probability this depth will first be reached next to the headland — and the wave front will tend to bend here first. The energy of the waves is concentrated on the headland and erosion takes place.

Fig. 6.8: The straightening of a beach under the influence of storm waves.

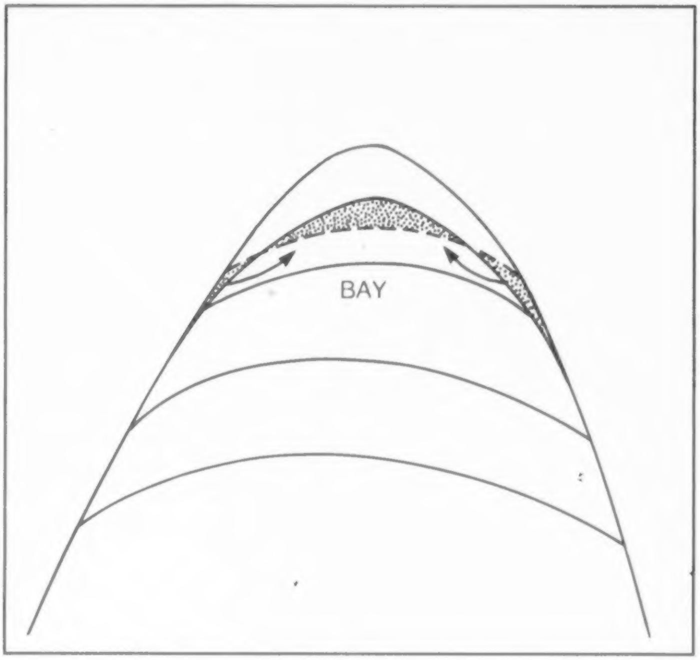
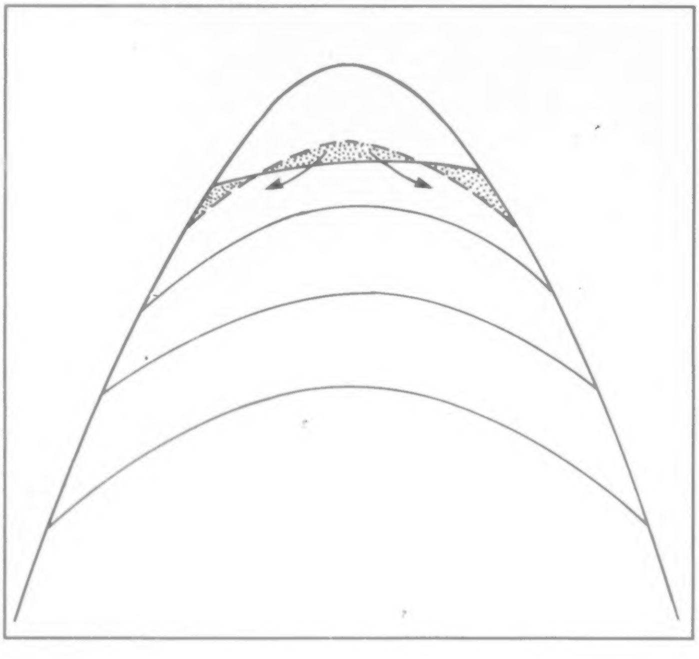
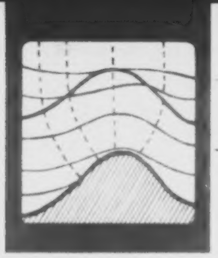


Fig. 6.9: Movement of beach material on return of normal wave regime.





Chapter six

Marine erosion and erosional features

The erosional effect of waves is not felt until the depth of water is in the vicinity of half a wave-length. Most of the energy associated with wave action is expended in the zone between plunge point and the shore.

The processes of marine erosion

- **Hydraulic action**
  The energy of the waves may be transmitted to the coast by wave impact itself. Actual pressures exerted by waves at places on the west coast of Scotland reach a maximum of 32 tonnes per square metre. It has been observed that such pressures can break loose and move blocks of bedrock outlined by joints and bedding planes. Such actions can be seen along much of the Tasmanian coastline, for example at the Blackmans Bay **blowhole.** Hydraulic action was probably responsible for the destruction of the jetty construction at Piccaninny Point on the East Coast of Tasmania early this century. The wharf was built with the thought of using it as an outlet for the coal mined on the East Coast. However, because of the coast's vulnerability it was no sooner built than it was destroyed.

  Hydraulic action is aided by the air which is compressed as the water sweeps into joints and fractures in the bedrock. Recession of the water is accompanied by the sudden expansion of the air with a tremendous explosive force which can often be heard as a deep thud. This impressive evidence of wave action is evident at Blackmans Bay and on the Tasman Peninsula. The water driven into the rock crevices not only exerts great mechanical stress, it also accelerates solution processes.

- **Abrasion**
  The abrasion of rock surfaces by wave-driven particles is one method by which coastlines are eroded. The sand and pebbles moved by the waves are hurled against the solid rock with great violence. In a less spectacular process, the surf also drags the rock fragments backwards and forwards over the bedrock. This results in a smooth floor or platform, and the rock particles themselves are smoothed, rounded and made smaller.

- **Chemical and biological erosion**
  The significance of the chemical action of sea water has generally been underestimated. Chemical attack is an important process in marine planation; for example, chemical processes become much more important than mechanical ones in warmer latitudes. Even in Tasmania a good deal of **shore-platform** formation takes place by solution processes.

  Many strange coastline features around the island, (e.g. Pt. Hibbs) owe their origin to the chemical action of the sea. The preliminary results of a shore-platform reconnaissance in Tasmania (Sanders 1965) suggests that biological and biochemical activities are important in platform lowering and levelling.

- **Attrition**
  This results in the wearing down of the cutting tools themselves. It contributes to abrasion by reducing rock particles to sizes within the range of competence of the wave action. These particles then form a portion of the cutting tools.

Variation in wave strength is not the only factor that influences the rate at which marine erosion proceeds. Among other controlling factors are:

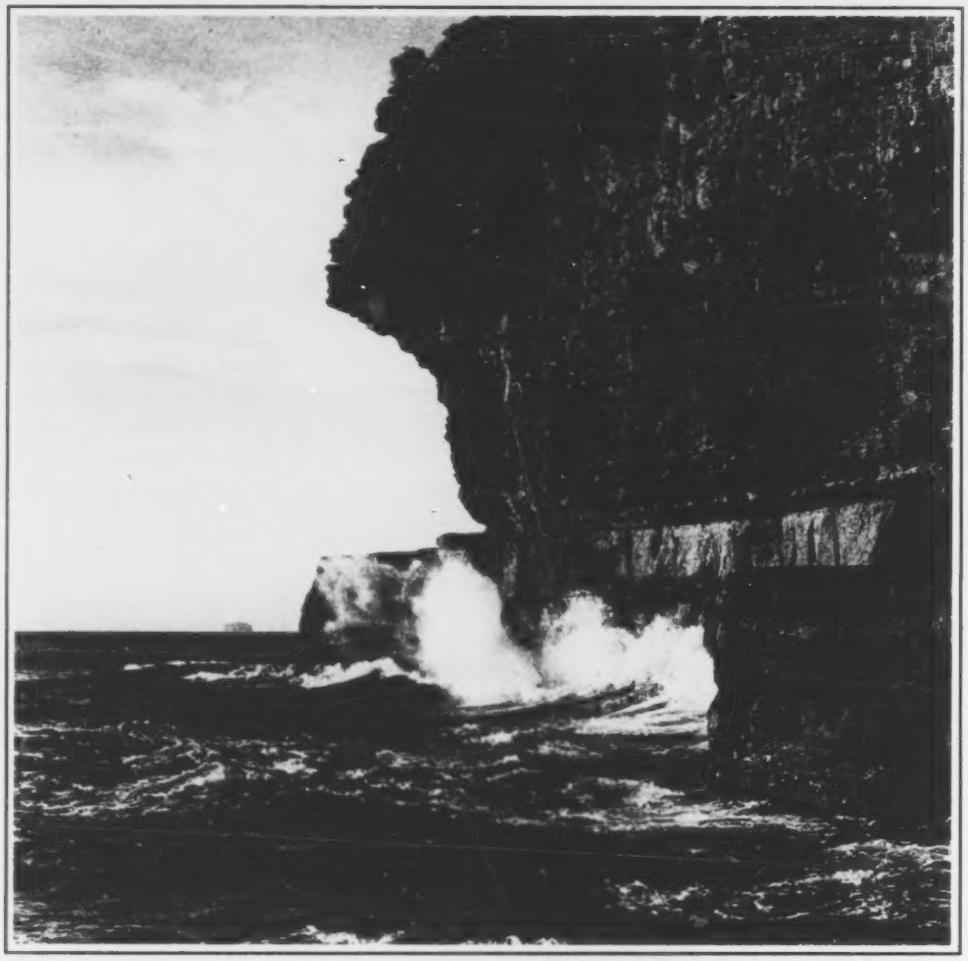
- *the kind and durability of the rock along the shore line;*
- *the structural features of the rock, its strike and dip, and degree of jointing and fracturing;*
- *the degree of exposure to coastal attack;*
- *the abundance and size of the abrading load;*
- *the depth of water offshore. If due to the underwater contours, the plunge point is nearer to the shore, the energy is expended in a small area and hence erosion is more rapid than where the underwater coastline has a more gradual slope;*
- *the abundance and type of marine life present.*

Erosional features— the shore profile

It was once considered that sea cliffs were formed by the mechanical formation of a

notch or **nip** at the base of the cliffs. Notches at the base undermined the cliffs. But most authorities now consider that **solution**, rather than the mechanical forces of abrasion and hydraulic action, is the important factor in the formation of the notch. It has been observed that the most spectacular notches occur in tropical limestones (e.g., coral), where solution and not abrasion is the significant process.

Fig. 6.10: Wave action at Eaglehawk Neck.



It is for this reason that the descriptive terms **sea cliff** and **shore platform** are preferred to the terms 'wave-cut cliff' and 'wave-cut platform'. The profile of the sea cliff depends, to a large degree, on the type and structure of the rock in which it is cut (see figure 6.12).

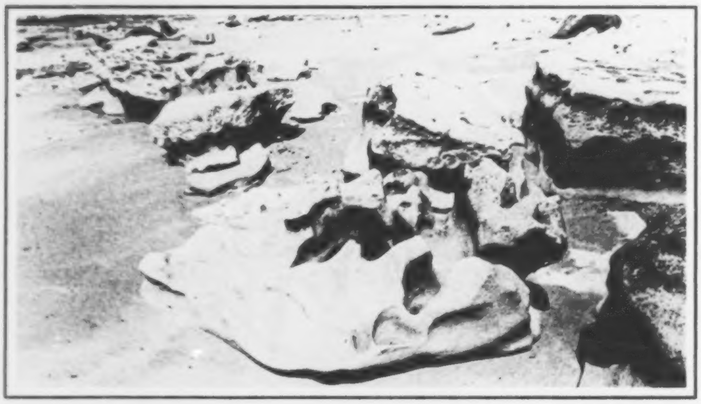


Fig. 6.11: Solution action of sea water on a Tertiary calcareous sandstone near Fossil Bluff, Wynyard.

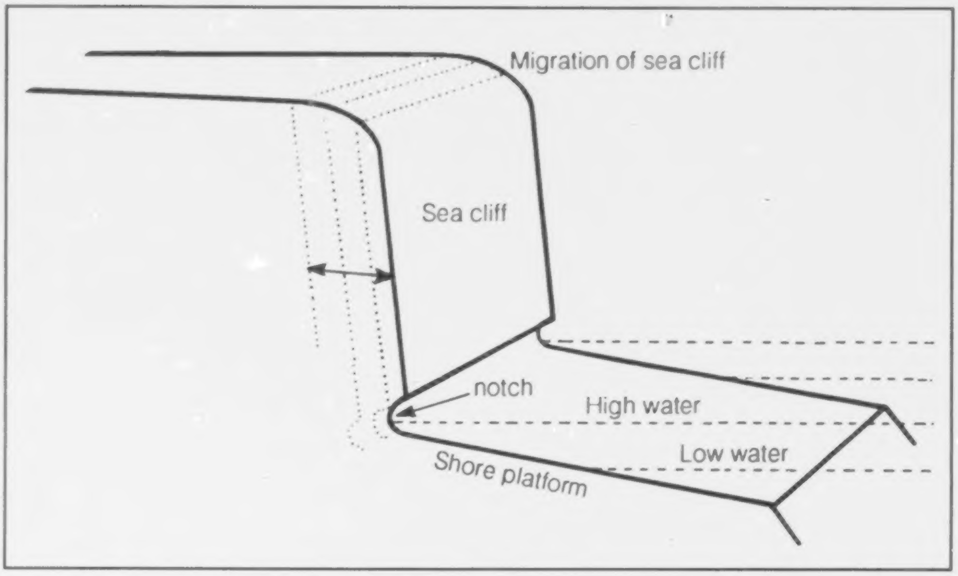


Fig. 6.12: Relationship of the important erosional features - sea cliff, notch, shore platform.

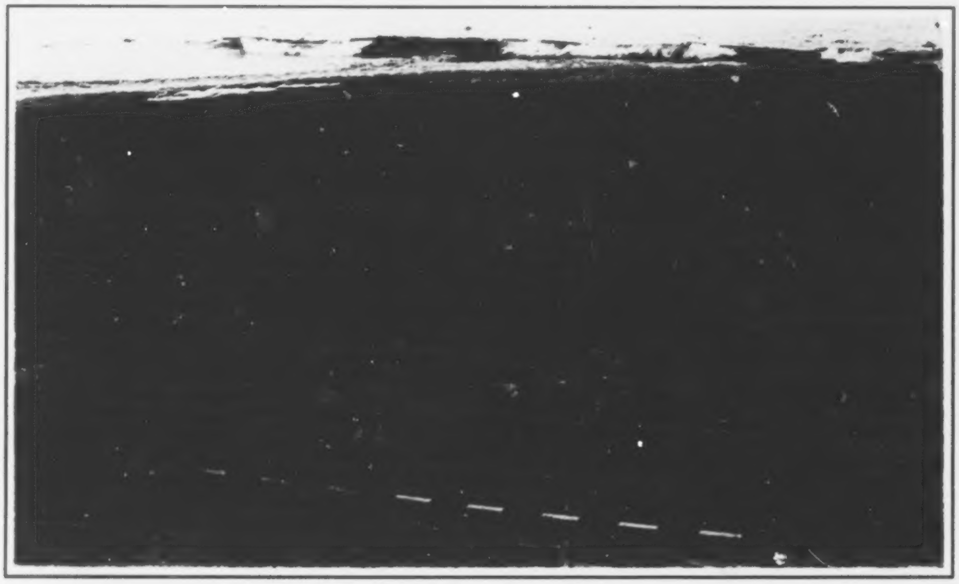


Fig. 6.13: The tessellated shore platform in Permian mudstone at Eaglehawk Neck.

Sea cliffs

Although, generally speaking, the coastline of Tasmania is extremely rugged, it is also extremely variable. For example, cliffs which have been cut in rocks dipping seaward are very different from cliffs which have been formed in rocks dipping landward. The latter structure may be in the form of a **cuesta** in which the seaward slope is much greater than the dip slope of the sediments.

Cuestas are found in the Blackmans Bay and Tasman Peninsula regions. Here the vertical sea cliffs are determined by the presence of vertical joints, which also account for the absence of any pronounced notches along these coastlines. Similarly, the well-jointed Jurassic dolerite, which is an important rock of the coastline of south-eastern Tasmania, features as steep sea cliffs at places like Cape Raoul and Maatsuyker Island.

The cliffs cut in granite on Freycinet Peninsula differ quite markedly from those cut in the basalt of the Penguin area. In the latter case, landslides are common and a shore platform has developed. Cliffs eroded in the soft Tertiary deposits at Wynyard are marked by much slumping and land-sliding.

It must be stressed that Tasmania's impressive sea cliffs may not be the direct result of the present erosional cycle. Much of the erosion may have occurred in the last interglacial period.

Shore platforms

As the sea cliffs retreat, shore platforms are produced. These generally slope gently seaward, as at Burnie, but the slope depends on the structure of the rocks concerned.

For example, at many places around Blackmans Bay the platform has been cut along where a dolerite sill comes into contact with the Permian Grange Mudstone which dips gently inland. As a result, the shore platform also dips gently inland. As the cliff retreats, the bench grows in a landward direction. The platform may be bare or covered partly with sediment. The sediment is dragged to and fro, polishing and smoothing the surface.

The landward sides of many benches are exposed at low tide, and in Tasmania, coastal uplift has caused the emergence of some former shore platforms. One picturesque example is that of Pyramid Rock, north of Pt. Hibbs. Other examples occur at 9 metres to 12 metres at Godfrey's Bay near Stanley and at 6 metres to 10 metres between Hawley and Port Sorell.

It seems that in Tasmania some rocks tend to form shore benches much more readily than others. For instance, where granite outcrops along the coast, and where dolerite alone forms the coast, benches are rarely produced to any extent. This is particularly noticeable on Freycinet Peninsula and around Blackmans Bay.

The basalt flows on the north-west coast of Tasmania have exercised some control over the profile of the coastline. During the Tertiary Period lava filled the deeper parts of the old valleys and frequently extended below present sea level. Subsequent marine erosion has produced a scarp coast with cliffs 60 to 90 metres high backing a narrow shore platform. This is well shown at the Don Heads and between Table Cape and Boat Harbour.

Sanders (1965), observing the Tasmanian coastline, concluded that points pounded by the south-westerly swells have high shore platforms with distinct seaward slopes.

The low platforms of the Bass Strait coast have a greater average seaward slope than platforms in similarly sheltered southern areas where the tidal range is halved. Tidal range seems to have an important influence on the development of shore platforms.

Because of wave attack, sea cliffs will recede at different rates along a coast. The rate of recession will depend on the differential resistance of the rocks making up the coast-

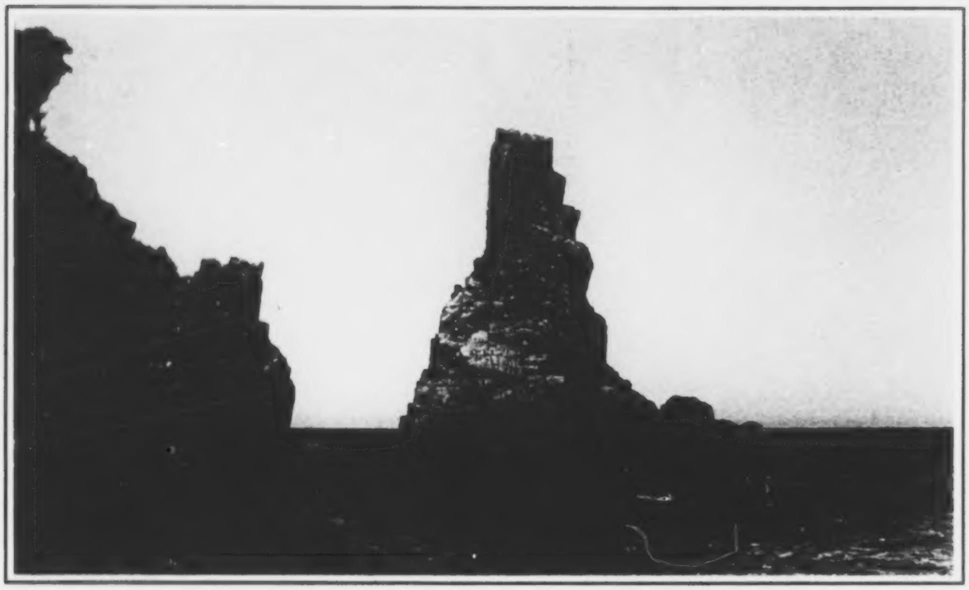


Fig. 6.14 : Pyramid Rock on the southern tip of South Maria Island.

line. As a result, many small coves and bays have been produced by erosion of the less resistant sediments or of the areas of intense jointing or along a fault zone. Numerous examples of the differential erosion may be found around the Tasmanian coastline. The tunnel profile of Remarkable Cave, Tasman Peninsula, is controlled by jointing and bedding. The seas eroded along a zone weakened by jointing and the roof at the back of the tunnel collapsed. The small bay immediately south of Blackmans Bay has been eroded along a fault. In other cases, bays may be found along fault zones which were possibly eroded by streams whose valleys have since been drowned.

However, it is doubtful if wave attack is ever responsible for large bays and estuaries. These have resulted from submergence of topography produced in other ways. Such is the origin of the Derwent estuary. Headlands or promontories are left in areas of more resistant rocks, or are the remnants of hills of a pre-drowning landscape.

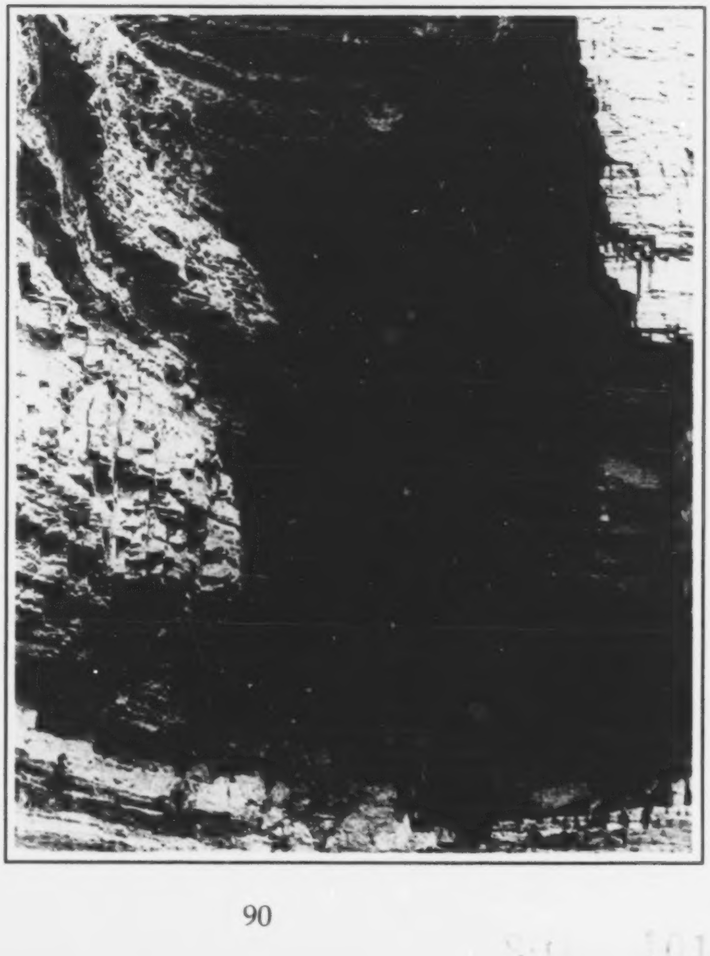


Fig. 6.15: A cave, Tasman Peninsula. The sea has eroded along a zone weakened by jointing.

Sea caves

The headlands subsequently subjected to wave attack from two sides may have sea caves cut in them. As has been explained previously, headlands tend to be eroded much more rapidly than bays because of refracted wave fronts. The energy of the waves is concentrated on either side of the headland. As a result, small sea caves are driven in on either side of the headland, particularly if weaknesses such as joints or faults are present to facilitate the process. Sea caves are prevalent along the coastline of Tasmania.

Sea arches

This process may continue in this fashion until the sea caves merge into one another. The resultant landform is known as an arch. Perhaps the most outstanding Tasmanian example of such a landform may be found south of Blackmans Bay. South of Verona, on the Channel Highway, Arch Island is an example of the same landform. Another sea arch occurs at Don Heads. Tasman Arch on Tasman peninsula has not been formed by the same process.

As a result of prolonged erosion, arches may eventually collapse and a stack results. At high tide stacks are separated from the headland by a narrow strip of water. Further erosion may result in the formation of new sea caves on the remaining portion of the headland. Stacks formed of varying types of rock abound around the Tasmanian coast.

Blowholes

Along the southern and eastern coastline of Tasmania, particularly around Blackmans Bay and Tasman Peninsula, conditions are admirable for the development of blowholes. The Permian rocks dip at a small angle away from the sea. The sediments are also well jointed, and wave attack is concentrated along these vertical weaknesses. Caves extend along these joints, and of course, the further they progress into the land the nearer they approach the surface. Eventually the roof of the deeply penetrating sea cave falls in, leaving an open funnel. Blocks of rock outlined by the bedding planes and joint systems fall into the cave and are used as agents of abrasion.

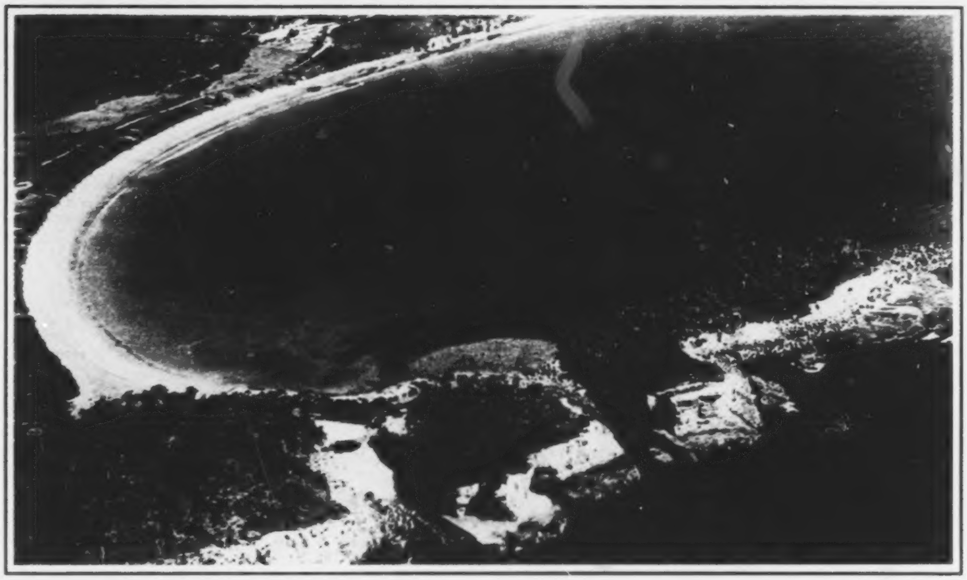


Fig. 6.16: The Blowhole area, Eaglehawk Neck. Horizontal beds and vertical joints control the marine topography of steep cliffs and shore platforms. The point is actually a stack in the early stages of formation.

The spectacular behaviour of a blowhole occurs when a blast of air and spray is projected up through the funnel as each wave enters the mouth of the cave. The blowhole at Eaglehawk Neck owes its attraction to this feature. At Blackmans Bay the blowhole is in a much older stage and due to hydraulic action and abrasion the funnel has become so large that this spectacular effect no longer occurs, except perhaps during great storms. Tasman Arch on Tasman Peninsula was initiated as a blowhole similar to that now found further north. However, although it is also at a much more advanced stage, it has lost little of its spectacle. The height of the natural bridge above water level may serve to indicate the tremendous force of the waves.

It must be emphasised strongly at this point, that the most important landforms resulting from marine erosion are the sea cliff and the shore platform, together with possibly the notch at the junction of the two forms.

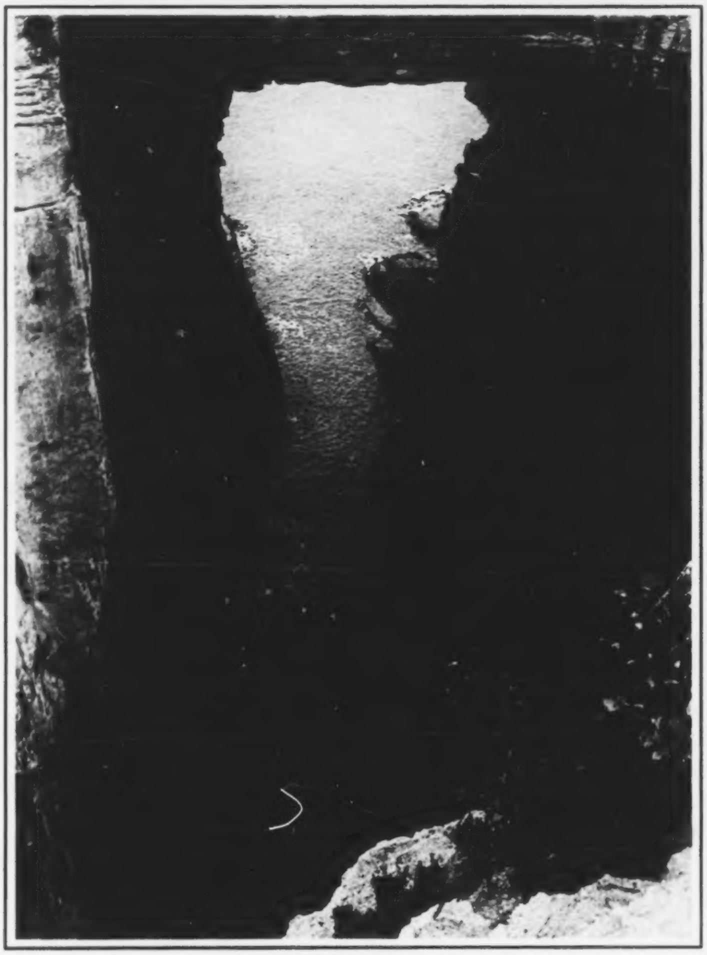
The other features cut in or from the cliff and platform, such as the sea caves, arches, stacks and blowholes are only minor irregularities and developments. Numerous abandoned sea cliffs (e.g. near Ulverstone) shore benches (e.g. near Stanley) and sea caves (e.g. near Rocky Cape) indicate that in comparatively recent times changes have occurred in the level of the land and/or sea level.

Marine deposition

The most common form of marine depositional feature is the **beach.** Although beaches are mainly limited to the heads of bays or coves, strictly speaking the temporary veneer of rock debris which collects on a shore bench should also be included under the same general heading. Many people consider it to be the sandy surface above water along the shore. However, this surface may also include the foredunes and dune ridges further inland.

A beach may be defined as a gently sloping shore adjacent to, off a body of water. It includes especially the parts covered by sand or pebbles and washed by waves. In this zone, the sediment actively moves, and as a result, its impermanence should be stressed. Some of the sediment constituting a beach is derived from the erosion of the sea cliffs, but most is contributed by stream discharge along the coastline. Much of the material being deposited at present day on Tasmanian beaches is being carried by shoreward drift of material delivered by streams which flowed to the sea during Pleistocene low sea level stands. In many places in the world beaches may extend continuously for hundreds of miles along a shore, but in Tasmania the rugged shore line limits the formation of beaches to strips at the heads of bays or coves. Such beaches are most often called **bayhead beaches.** Beaches are formed in dynamic equilibrium with the incident waves and their form depends on the amount and type of sediment available and the energy characteristics of the waves.

Fig. 6.17: Tasman Arch, Eaglehawk Neck. This is an old Blowhole formed in Permian sediments.



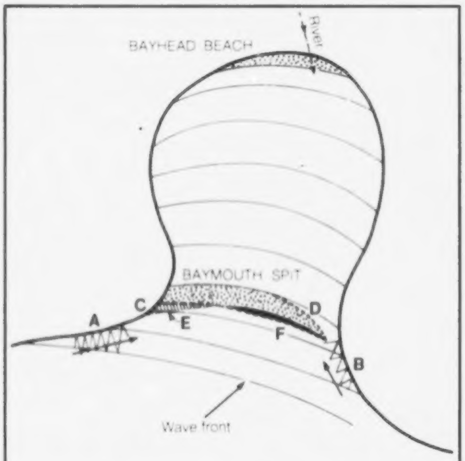
Bars, spits, barriers and lagoons

The term **bar** is becoming increasingly restricted to submerged banks of sand and gravel built on the sea floor by waves and current. A **spit** is an emergent ridge of sediment attached to the land at one end and terminating in open water at the other. If the spit entirely closes off a body of water it is then known as a **barrier.** The body of still water enclosed by a spit or barrier is called a **lagoon**. In Tasmania, few barriers exist because small tidal currents, together with any river run-off, keep open a channel between the end of a spit and the adjacent land. Two barriers occur in the islands in Bass Strait. Burnett Lagoon on Flinders Island is dammed by one barrier and a similar barrier exists on East Cape Barren Island.

Formation of spits

Spits formed across the mouths of bays are called baymouth spits. The formation of these spits is explained by means of figure 6.18. A wave system entering a bay may not have sufficient energy to carry all of its suspended material to the head of the bay. When this occurs material may be dropped at the mouth. As the wave front is oblique to the coast at **A**, material is moved by longshore drift to a point where it has insufficient energy to continue movement of the material — say point **D**. It might here be noted that similar longshore drift occurs from point B towards the bay. However due to river run off and small tidal currents, such deposited material may be removed further out to sea. Under ideal conditions area **E** of the Spit would be removed by longshore drift to be deposited at area **F.** That is, the plan of the baymouth spit, as the deposit is called, would parallel the wave plan. Under normal conditions, of course, area **E** would continually be filled by longshore drift from **A,** although the tendency towards equilibrium conditions would still persist. A similar explanation might be given for a mid bay spit which is simply the same type of landform in a "bay within a bay" (Fig. 6.19).

Fig. 6.18: Formation of a baymouth spit.



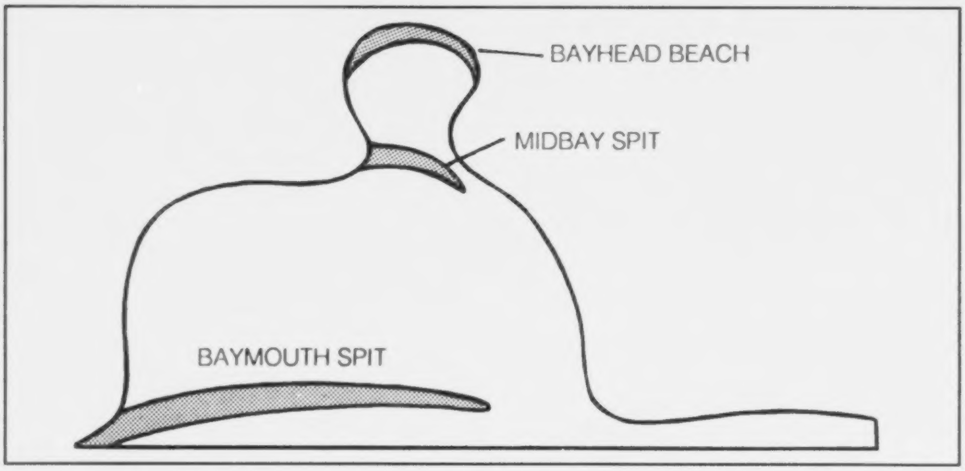


Fig. 6.19: Position of formation of a mid bay spit.

The baymouth spit at Marion Bay is about 8 kilometres long . Similarly the wide Rubicon River at Port Sorell is partly closed by a large baymouth spit.

It has been shown that this and other beaches and spits on the northwest Coast could be interpreted in terms of adjustment to the wave fronts of refracted swell split by King Island. The obliquely impinging waves from the west are responsible for generating the longshore drift from west to east.

Nine Mile Beach is a baymouth spit which almost encloses the head of Oyster Bay. As with the spits at Marion Bay and Port Sorell in the last interglacial, it testifies to the stability of the present dominant wave regime. As with the other two examples, a series of sand ridges may be observed behind and parallel to the spit itself. These represent old beach berms upon which windblown sand has accumulated.

Other baymouth spits occur at the mouth of Macquarie Harbour, New River Lagoon, Southport Lagoon, North Bay (Tasman Peninsula), Seymour, Falmouth, Diana Basin, Skeleton Bay, Anson's Bay, Mussel Roe Bay, Turner's Beach, Logan Lagoon (Flinders Island), Cameron Inlet (Flinders Island) and in the north east of Flinders Island.

Seven Mile Beach is a mid bay spit across the drowned mouth of the Coal River and standing at the head of Frederick Henry Bay. As with most other spits and beaches in Tasmania, it is built of sand. It is also backed by foredunes and sand ridges, and has grown up between an old interglacial shoreline and the present day shoreline. It is interesting to note that the hill on which the control tower is situated at Llanherne was a tied island during the last interglacial.

During the early Holocene it was incorporated into the embryo spit which has been forming since that time. The spit probably grew from west to east.

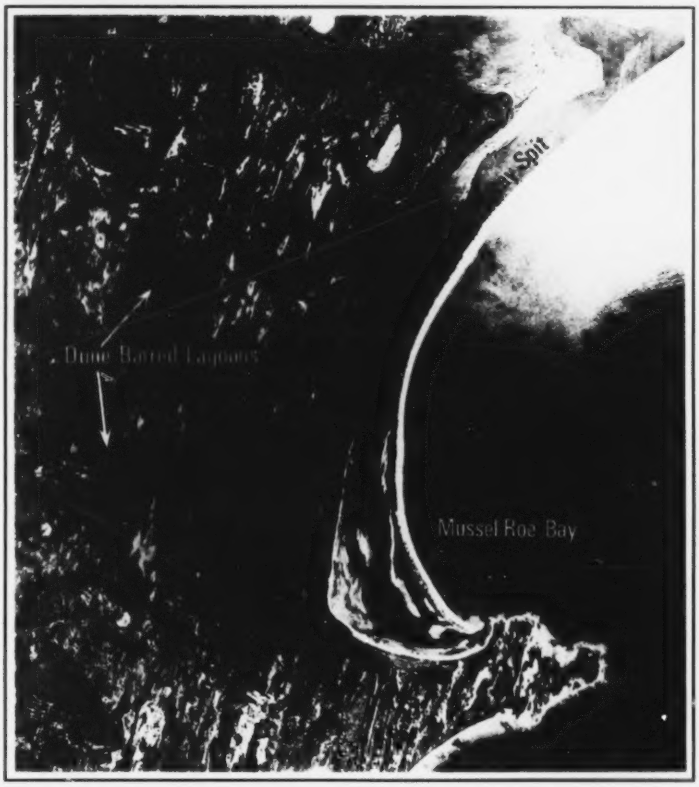


Fig. 6.20: A mid bay spit at Musselroe Bay in north east Tasmania. Dunes and dune barred lagoons are also well developed.

The swell reaches Seven Mile Beach parallel to the shore. Although the actual energy potential of this swell is small, it alone is responsible for building the beach berm and lines of sand beach ridges which determine the alignment of the spit as a whole. The short storm waves tend to erode the upper beach and cause kinks in the regular curve of the beach, but normally this damage is soon repaired by the dominant swell. All the other beaches in Frederick Henry Bay fit the refraction pattern. Another mid bay spit separates Cloudy Lagoon from Cloudy Bay at Bruny Island.

Tied islands and tombolos

In Tasmania many islands are tied together or to land by growth of one or more spits. Such islands are called **tied islands** and the depositional feature which ties the islands is called a **tombolo**. In the vicinity of Hobart, the South Arm peninsula consists of a series of former islands tied by marine deposition at several former high sea levels. Ralphs Bay Neck had its origin when the higher interglacial sea level began to build two spits across the strait that separated South Arm from the Sandford Peninsula. The two spits grew simultaneously and afforded each other mutual protection. Finally when the sea dropped, numerous beach ridges were formed along the line of the spits.

Many other examples of tied islands may be noted around the coast of Tasmania. The two halves of Maria Island and North and South Bruny Islands are tied by tombolos. The tie barrier connecting North and South Maria Island is a sandy isthmus separating Reidle Bay from Oyster Bay. The tombolo is about a hundred metres across and at the most 4.5 metres above high water mark. Similarly Freycinet Peninsula is tied to the Hazards by a tombolo west of Wineglass Bay. On a small scale, Frying Pan Island at Berriedale, north of Hobart, is a tied island. On the north west Coast, the Nut at Stanley is tied to the mainland by two spits which were produced by the southern section of the south westerly swell split by King Island.

Barrier islands

Barrier islands are elongated sand islands offshore, parallel with, but not connected to, the coast. They are not to be found around the coastline of Tasmania at the present time, but there is evidence that an old barrier island exists in the vicinity of South East Lagoon, King Island.

Such islands are often initiated offshore, particularly in coastal regions with shallow seas. Some may be due to rapid emergence and dissection of offshore bars during rapid emergence in a marine regression, yet others may be formed by shoreward sweeping of sediment during a marine transgression. Others may have originated and survived during minor emergent phases of an oscillating transgression.

Barrier islands in southeast Australia are of recent age, having been formed during and since the Holocene marine transgression. Barriers are best developed where the tide range is low, but islands are more common where gaps through the barriers are kept open by outflowing rivers or by strong ebb and flow currents in a high tidal range regime.

At King Island, associated with an old sea level at 15 metres, a barrier island was built up by wave and wind action as a sand ridge. A lagoon was present behind this ridge and after emergence the lagoon became a fresh water swamp and lake.

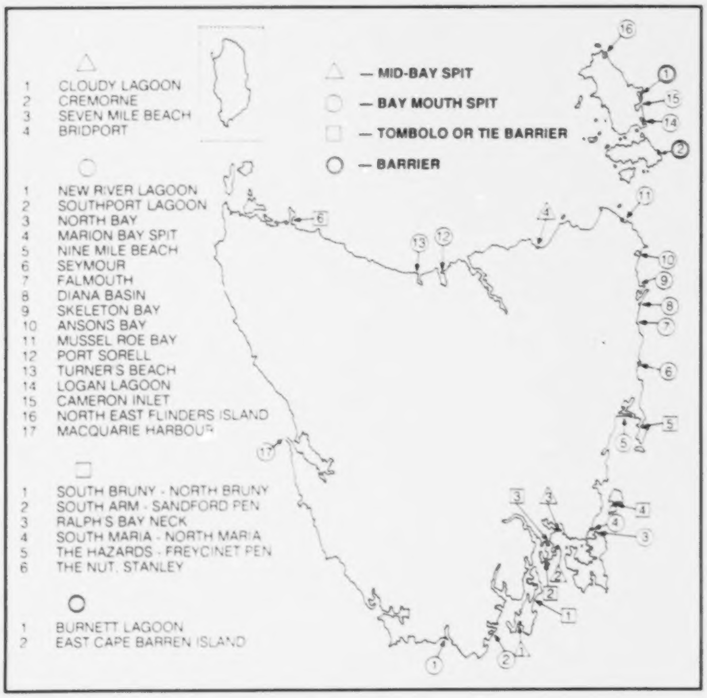

△
1 CLOUDY LAGOON
2 CREMORNE
3 SEVEN MILE BEACH
4 BRIDPORT
○
1 NEW RIVER LAGOON
2 SOUTHPORT LAGOON
3 NORTH BAY
4 MARION BAY SPIT
5 NINE MILE BEACH
6 SEYMOUR
7 FALMOUTH
8 DIANA BASIN
9 SKELETON BAY
10 ANSONS BAY
11 MUSSEL ROE BAY
12 PORT SORELL
13 TURNER'S BEACH
14 LOGAN LAGOON
15 CAMERON INLET
16 NORTH EAST FLINDERS ISLAND
17 MACQUARIE HARBOUR
☐
1 SOUTH BRUNY - NORTH BRUNY
2 SOUTH ARM - SANDFORD PEN
3 RALPH'S BAY NECK
4 SOUTH MARIA - NORTH MARIA
5 THE HAZARDS - FREYCINET PEN
6 THE NUT, STANLEY
○
1 BURNETT LAGOON
2 EAST CAPE BARREN ISLAND
△ — MID-BAY SPIT
○ — BAY MOUTH SPIT
☐ — TOMBOLO OR TIE BARRIER
○ — BARRIER

Fig. 6.21: Map of Tasmania showing depositional features around the coastline.

History of the Tasmanian coastline

In the Late Cretaceous - Early Tertiary the break of Antarctica from Australia caused crustal fracturing and earth movements that have given Tasmania its particular shape and physiography. The great rift valley forming the Bassian Depression (Fig. 6.22) of Bass Strait was probably in existence in the Eocene Epoch and was certainly present in the Middle Miocene.

Other major features are a series of North-South trending horsts and grabens such as the Derwent, Oyster Bay and Launceston grabens. It is of interest that Bass Strait has formed where the dolerites cease. No dolerite of Jurassic age outcrops on the islands of Bass Strait or in Victoria.

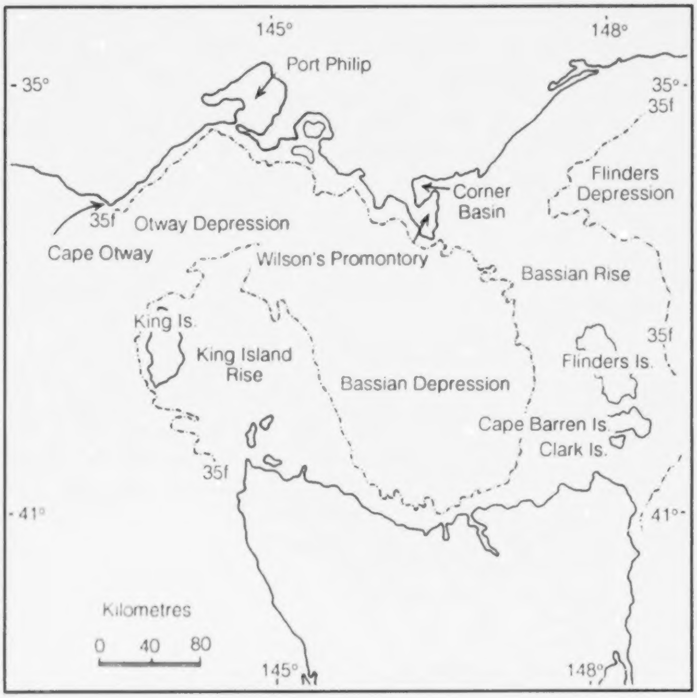
The land link between Tasmania and the mainland of Australia was recreated at least two times during the Pleistocene Epoch. There is ample evidence to demonstrate that there were at least two cold climatic stages in the late Quaternary during which ice caps and glaciers were present in western Tasmania and in the higher altitudes of Tasmania. A warmer climatic stage, the Last Interglacial, occurred between the last two glacial stages.

During glacial stages lowering of sea level, caused by formation of large ice masses elsewhere, created a land bridge across Bass Strait. Flooding of Bass Strait occurred during each interglacial and since the Last Glacial.

The major outline of the coast of Tasmania, particularly the south and southeastern parts results directly from this world-wide post glacial rise in sea level. The effect of the rise has been quite marked in southeast Tasmania. It drowned the Derwent and Pittwater valleys and flooded the lowlands of Ralph, Frederick Henry, Norfolk and Blackman Bays.

This last event initiated the present cycle of marine processes. Since this time the sea has modified the initial coastline by the cutting back of headlands, removing slope deposits, and the building of spits and tidal marshes. During this modification, smaller changes of sea level have occurred, however, these have had only very limited effect.

Fig. 6.22: The major features of Bass Strait. These features, tectonic in nature, are oriented along NW-SE and NE-SW lines.



Climatic warming at the end of the Last Glacial and in the early Holocene led to the present climatic conditions.

Upper Pleistocene high sea level stands (Last Interglacial)

Some high marine levels identified on King and Flinders Islands and in northeastern Tasmania lie above 22 metres. The majority of evidence, however, is for deposits believed to have been formed during the Last Interglacial when relative sea levels reached a maximum of approximately 22 metres above present mean sea level. Fossil evidence suggests that water temperatures during the Interglacial may have been slightly warmer than at present.

Many sea level stands of Last Interglacial age have been identified around the Tasmanian coastline. Between Strahan airport and Ocean Beach and at Dead Horse Point, marine terraces approximately 20 metres high represent one marine level that has since been fragmented by erosion. Eighteen to twenty two metre shorelines have been identified from Swan Basin to Strahan. Northwards along Ocean Beach these high level shorelines have been obscured by dunes formed during and since the Last Glacial.

On the gently shelving coast of the Smithton area there is evidence for a maximum marine transgression of 20 metres with a long gradual recession to below present sea level during the early part of the Last Glacial stage. This gentle shelving of the coastline probably forms the foundations of the extensive shallow offshore areas off North West Tasmania. In the same area at Rocky Cape there are emerged sea caves, formed when the sea level was approximately 21 metres higher than at present.

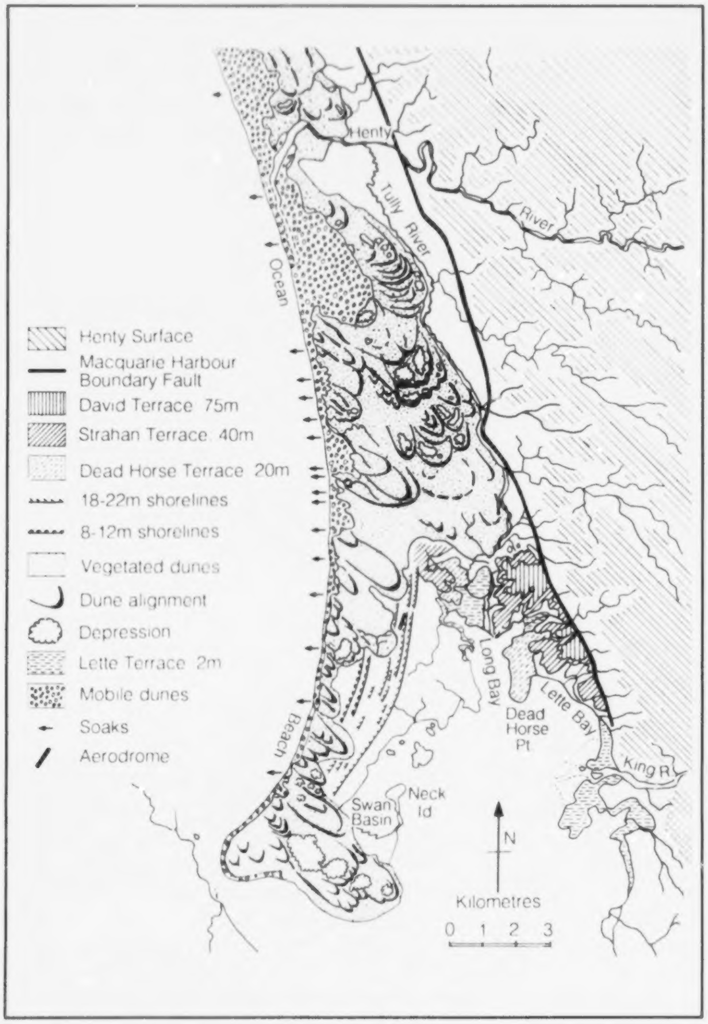

Henty Surface
Macquarie Harbour Boundary Fault
David Terrace 75m
Strahan Terrace 40m
Dead Horse Terrace 20m
18-22m shorelines
8-12m shorelines
Vegetated dunes
Dune alignment
Depression
Lette Terrace 2m
Mobile dunes
Soaks
Aerodrome
Henty
Tully River
River
Ocean
Beach
Long Bay
Lette Bay
Dead Horse Pt
King R
Swan Basin
Neck Id
N
Kilometres
0 1 2 3

Fig. 6.23: Map of aeolian features, shore lines and terraces near Strahan.

On the North West coast between Circular Head and Port Sorell, old sea levels are again indicated by marine deposits up to a maximum of 22 metres above high water level. Marine foreshore terraces and storm shingle bars occur between heights of six and sixteen metres at the mouth of the Forth Valley.

In the Ulverstone area, Chick (1971) has recognised and named extensive depositional terraces and other shoreline features up to fourteen metres above mean sea level. Other erosional features occur at high levels but have been obscured by deposition, destroyed by downslope movement of slope deposits, and have been subject to erosion, making them difficult to investigate.

In North Eastern Tasmania between Bridport and Eddystone Point marine sands containing sponge spicules occur up to 30 metres and form extensive gently seaward sloping coastal plains that have in part been masked by WNW - ESE trending linear dunes and lunettes. Prevailing winds during the Last Glacial between 22,000 and 15,000 years B.P. led to the formation of extensive dune fields not only in N.E. Tasmania, but also in the West, North West and East.

Remnants of marine deposits occur at several localities on the East Coast, particularly between St. Helens and Swansea and on the margins of the drowned coastline of the South East. Maximum transgression levels are again indicated by a figure of 22 metres at Mary Ann Bay.

The Llanherne Level

Davies (1959) suggested a widespread marine level at 3 to 5 metres which he called the Llanherne Level, but although there are many marine deposits at this level they also extend without significant breaks to 20 - 22 metres at South Arm, Bruny Island, Mary Ann Bay and many other areas around the state coastline.

Although many different levels have been identified around the coast it has not yet been possible to correlate the marine sediments with specific sea levels. Colhoun (1975) believes the Llanherne Level represents the floors of sandy pocket bays that existed between headlands. In many places deep water would have stood directly against cliffs and steep hillsides and the offshore sediments at their bases would not have had constant depth relationships at different localities with the contemporary sea levels.

Below the well defined upper limit of 22 metres there are depositional terraces and rock platforms at all levels to, and even below, present sea level. It is not possible to correlate the features on a height basis for any extensive stretch of coast or for the whole island. What is known, however, is that during the Last Interglacial a major marine transgression took place that attained a maximum level of 22 metres and deposited sediments on the floors of gently sloping bays. This was followed by a continuous, uniform regression to below present sea level without any significant stillstand during the last part of the Last Interglacial and in the early part of the Last Glacial.

Emphasis must be placed on the continuous nature of the regression to explain the almost continuous range of beach ridge sequences for the marine sediments found around the coastline, but particularly evident on Robins Island and in the Smithton area.

The maximum heights for transgression in Tasmania differ significantly from those in other parts of the world. These averaged about 7.5 metres above mean sea level. This difference in height cannot be explained in terms of rising sea level only. It indicates a tectonic uplift of Tasmania since the Last Interglacial.

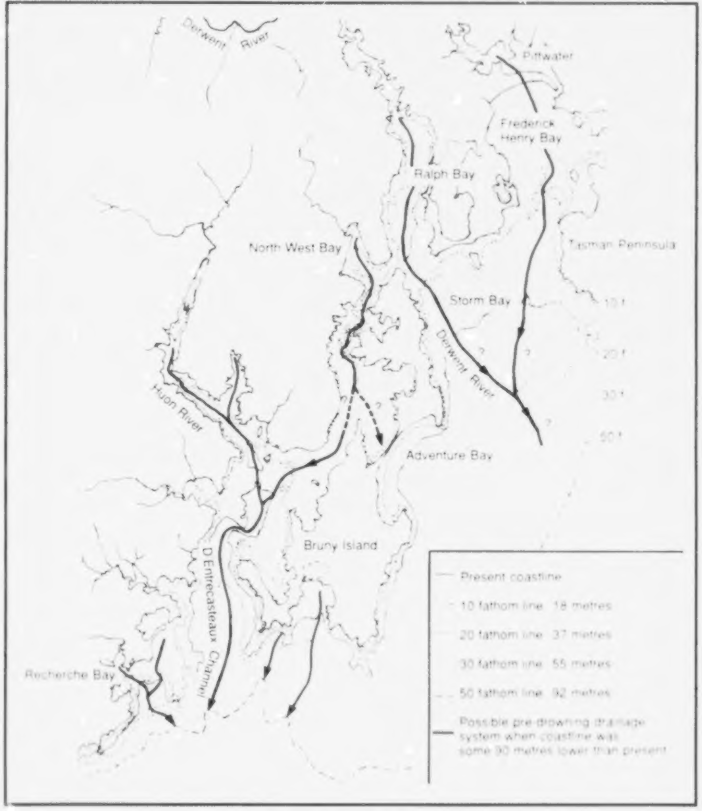
The Last Glacial Stage (25,000 - 10,000 B.P.)

A gradual recession of sea level led to a draining of Bass Strait and caused an increase in the area of Tasmania.

The gradual lowering of temperatures and associated increased wind velocities and increased continentality of Tasmania led to a climate dominated by an active northwesterly airstream which transported large quantities of marine sediments from previous offshore localities to form extensive dune fields in many coastal areas.

Jennings (1959) described old coastal dunes in 37 to 46 metres of water off N.E. Flinders Island, but Colhoun (1975) queries their genesis and suggests they may be terrestrial dunes formed on the floor of Bass Strait during the Late Last Glacial when the sea level was low.

Sections across the Derwent River near Hobart show a mudfilled channel cut in bedrock to a depth of about 53 metres below present sea level. This evidence implies a strand line at least 60 metres lower than that which exists today. A clearly defined, submerged, mud-filled and apparently river-cut channel runs, from east to west from Norfolk Bay into Frederick Henry Bay, reaching a maximum present depth of 45 metres immediately to the north of Slopen Island (Fig. 6.24). The channel contains an unknown depth of mud and hence the original depth must be assumed to be something in excess of this. A submerged stream channel between the Blowhole and Cowper Point on King Island also indicates a low sea level stand. At Hell's Gates, a little downstream from Corinna, the floor of the Pieman River is 40 metres below sea level.



Derwent River
Pittwater
Frederick Henry Bay
Ralph Bay
North West Bay
Tasman Peninsula
Storm Bay
Derwent River
10 f
20 f
30 f
50 f
Huon River
Adventure Bay
Bruny Island
D'Entrecasteaux Channel
Recherche Bay
?
Present coastline
10 fathom line 18 metres
20 fathom line 37 metres
30 fathom line 55 metres
50 fathom line 92 metres
Possible pre-drowning drainage system when coastline was some 90 metres lower than present

Fig. 6.24: D'Entrecasteaux Channel and the Derwent River. Possible pre-drowning drainage system when coastline was some 90 metres lower than present.

The rivers of Northern Tasmania (e.g. Tamar River, Rubicon River at Port Sorell, Forth River, Leven River) have been cited as evidence of Pleistocene low sea level stands. Similarly the estuaries of the Derwent and Huon Rivers in southeastern Tasmania (Fig. 6.24) and of Bathurst Harbour in the southern part of the island, testify to a low sea level during the Late Last Glacial.

Holocene (10,000 B.P.)

A gradual warming of the climate after the Late Last Glacial caused flooding of Bass Strait until, during the Mid-Holocene, sea level reached its maximum height of about 2.5 metres above present mean sea level in North West Tasmania and less than 0.5 metres in Southern Tasmania.

The building of spits to close bays and of tidal marshes behind the spits, was part of the cycle of erosion following submergence of the coastline. Perhaps the most spectacular examples of this are the spit at Marion Bay and the neck at Ralphs Bay. The spit at Pipe Clay Lagoon, Cremorne, grew from this level.

This difference in height could be explained by marine deposition within the greater tidal limits on the N.W. Coast (3 - 4 metres) compared to the South East (less than 1.5 metres), or by differential hydroisostatic adjustment of Tasmania caused by the removal of water in the Bass Strait area as a result of refreezing of world ice. Since the Mid-Holocene, the sea level has dropped to its present stand, and there is considerable argument in forecasting sea levels for the near future.

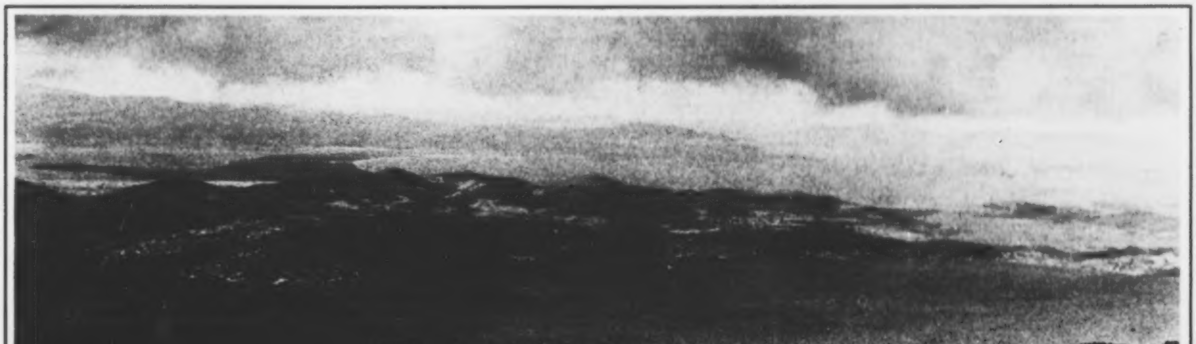


Fig. 6.25: The Derwent estuary from Mt. Wellington.

Chapter seven

Glaciation and Tasmania

Eric A. Colhoun and David Hannan

Introduction

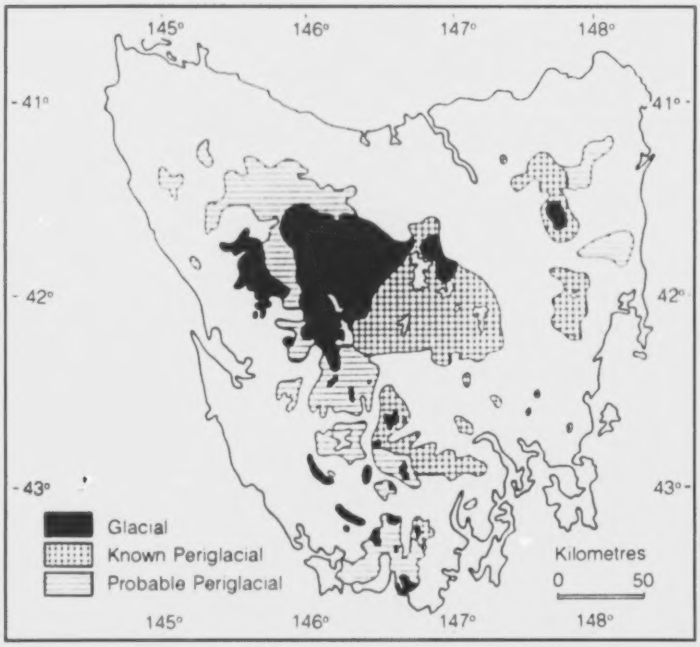
At present glacier ice covers approximately 11% of the earth's land area and includes the ice sheets of Antarctica and Greenland, and the glaciers of mountainous regions of all latitudes. A further 14% of land is frozen ground, which occurs mainly in Siberia, northern Canada, Alaska and Antarctica. In addition, extensive areas above the tree-line on mountains are strongly influenced by winter snow and by seasonal freezing and thawing of the ground. Collectively, these regions form the earth's cold environments, which not only have distinctive physical characteristics but also impose certain physical constraints on occupation and development.

At the maximum of the last glaciation, approximately 18,000 years ago, it is estimated that 30% of the land surface was covered by glacier ice. In addition to Antarctica and Greenland, large ice sheets were formed over northern North America and northwestern Europe, and mountain ice caps and glaciers were formed in Europe, Asia, North America, South America and New Zealand. Frozen ground was also much more extensive than today. Nearly all the U.S.S.R. and Europe north of the Alps had permanently frozen ground, as had parts of the north central U.S.A. In mountainous regions glaciers were much more extensive than present, and the zone in which snow and forest processes predominated extended to low elevations.

These broadscale environmental changes recurred many times during the last 1.8 million years of the Quaternary Period, as the climate changed from warm conditions during interglacial periods to cold conditions during glacial periods. During each period of glaciation much the same areas were affected by the development of ice sheets and glaciers, by permanent freezing of the ground, and by seasonally controlled snow and frost processes. The regions that experienced the greatest changes were the higher middle latitude (35 – 60°N and S) of both hemispheres.

Tasmania (40 – 44°S) experienced glaciation on at least three occasions during the Quaternary. On each occasion there were variations in climate, mainly temperature, which resulted in different amounts of glacial ice being formed, but in general the accumulations were in the same geographic areas. An ice cap was formed on the western parts of the Central Plateau and on the mountains of the Cradle Mountain-Lake St. Clair National Park. From this ice cap large outlet glaciers flowed northwards into the Mersey and Forth Valleys, and southwards into the Derwent. A smaller ice cap was formed on the West Coast Range from which outlet

Fig. 7.1: Distribution of areas affected by Pleistocene glacial and periglacial processes.



glaciers flowed westwards into the Pieman, Henty and Yolande Valleys, and southwards into the King Valley. In addition, most of the mountain groups of the southwest, which include Frenchmans Cap, Federation Peak, Frankland Range, Arthur Range, Mount Anne, Mount Field, Hartz Mountains, La Perouse and others, maintained small cirque and valley glacier systems. During an early stage of glaciation a small ice cap covered most of the Ben Lomond Plateau in the northeast.

Occupying a relatively low latitudinal position, Tasmania had only limited amounts of glacier ice during each glaciation and contributed only a very small part to the earth's glaciation. It is estimated that at the maximum of the last glaciation (18,000 years ago) there were over 1280 square kilometres of ice cover in Tasmania, and that maximum thicknesses were 300 to 450 m (Derbyshire, 1972). During the older glaciations the ice cover was more extensive and the ice was thicker, but the full extent awaits discovery and the precise ages have still to be determined.

Because of the maritime climate of Tasmania there were no extensive areas of permanently frozen ground beyond the limits of glaciation as occurs in northern hemisphere continental regions. Instead, seasonal snow and frost processes combined to produce many interesting phenomena in an alpine periglacial environment that was widespread throughout the mountains of the southwest and northeast, and operated for longer periods than each period of glaciation.

In studying the effects of past glaciation and associated snow and frost processes on the landscape of Tasmania we will consider:

- The way in which temperate glaciers such as those that occupied Tasmania form, and make some comparisons with polar ice sheets.
- The types of landforms that occur in mountainous regions where glacial erosion is intense.
- The types of deposits that are laid down, and the landforms that are produced by ice and its meltwaters in the valleys and lowlands adjacent to the mountains.
- Two areas where recent field research has demonstrated multiple glaciation in western and northern Tasmania.
- Some alpine periglacial landforms and deposits that were formed by the processes of snow and frost action in the mountains and valleys external to the glaciated areas.

The formation of glaciers and ice sheets

When the temperature decreases at the onset of a glacial phase in a temperate mountain area more of the annual precipitation will fall as snow. The snow may accumulate to considerable depths in valley heads and hollows on the leeward, shaded sides of the mountain crests. Here, the snow banks may be enlarged by more snow that is drifted over the mountain crests or off adjacent plateau surfaces by westerly winds, and they will be prevented from melting rapidly by the cool aspect of the sites. The accumulating snow banks will gradually be transformed into glacier ice. The transformation involves compaction and recrystallisation which result in an increase in density and a decrease in porosity as shown in Figure 7.2.

Compaction is caused by the weight of overlying snow and by wind pressure. Recrystallisation results from surface melting of the snow with percolation of water to depth where it refreezes, and to melting and re-

	Density g/cm^3	**Porosity %**
Fresh powdered snow	0.05 - 0.07	90
Wet snow	0.10 - 0.20	Variable
Settled snow	0.20 - 0.30	60
Windpacked snow	0.35 - 0.40	40
Firn	0.40 - 0.83	26
Glacier ice	0.83 - 0.90	10

Fig. 7.2: Changes in density and porosity as snow turns to glacier ice.

freezing due to changes of pressure within the snowpack and firn. These processes cause the snow particles to alter from star-shaped flakes to spherical granules called firn. The surface of a temperate glacier is covered with fresh snow, packed snow and firn above the firnline. The firnline is the upper limit of summer melting of all the previous winters' snow from the ice surface (Fig. 7.3). Once formed, firn is then further compacted and recrystallised to form glacier ice which has a density of 0.83 g/cm^3 and is non-permeable. Ice, nevertheless, still contains small air bubbles which give it its white colour. These are compressed as the ice density increases to 0.9 g/cm^3, which allows the ice to float though it is 90% submerged.

As the climate deteriorates during the glaciation the level at which permanent snow and ice can accumulate in the mountains becomes lower. The regional snowline, which is the average level of the firnlines of many glaciers, was some 1000 m lower in Tasmania during the last glaciation than it is today. It varied from about 700m in the southwest to over 1300m in the northeast and had a gradient of about 15m/km. Today the snowline lies 200 - 300 m above the highest peaks. As the snowline descended the glaciers would have extended further from the plateau and mountain source regions, and would have flowed through the adjacent valleys. As the extent of glaciation increased, the forms of glaciers that were developed in areas where the ice movement was constrained by the topography would have altered from niche through cirque to valley glaciers as indicated in Fig. 7.4. The ice caps would have occupied elevated plateau areas, as in central and western Tasmania.

When extensive ice caps have been formed the ice may flow from the high ground into the adjacent deep valleys and may form a reticulate network of outlet glaciers (i.e. valley glaciers connected directly with the ice cap). The glaciers of the Mersey and Forth Valleys were of this form. Where the glaciers flowed from the mountain valleys onto adjacent plains or low plateaux they formed **piedmont glaciers.** The Lake St. Clair glacier formed such a piedmont lobe in the Derwent Bridge area.

Above the firnline (Fig. 7.3) the glacier receives more snow than it loses each year and this part of the glacier has a positive budget. As a consequence the snow and ice flows from shallow to greater depths within the glacier. The glacier movement increases in speed towards the firnline, which approximately represents the line of equilibrium between gain and loss on the glacier. As

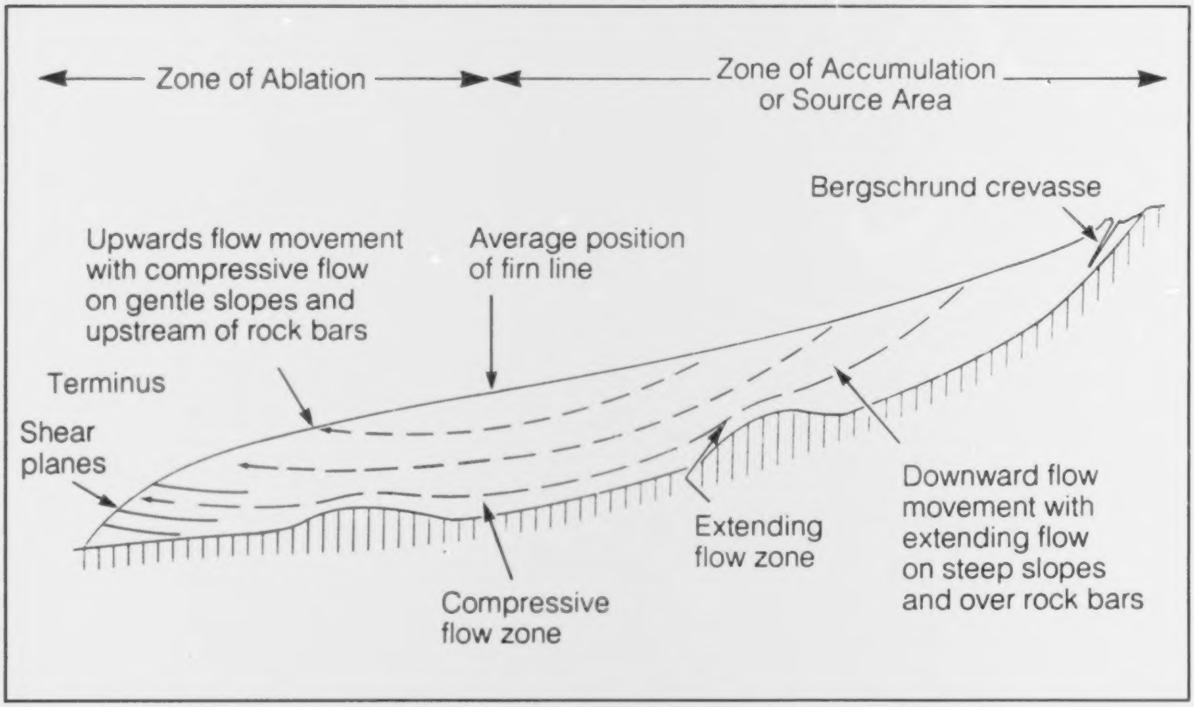

Zone of Ablation
Zone of Accumulation or Source Area
Bergschrund crevasse
Upwards flow movement with compressive flow on gentle slopes and upstream of rock bars
Average position of firn line
Terminus
Shear planes
Downward flow movement with extending flow on steep slopes and over rock bars
Extending flow zone
Compressive flow zone

Fig. 7.3: Cross-section of a typical temperate valley glacier.

	Type of glacier	**Accumulation site**
Glaciers constrained by topography	Small glaciers e.g. niche glacier	Small hollow on the side of a mountain
	Cirque glacier	Large circular hollow
	Cirque and valley glacier	Large hollow at the head of a valley
Glaciers usually constrained by topography	Outlet glacier	From ice cap or ice sheet
Glaciers unconstrained by topography	Ice cap	Plateau
	Ice sheet	Continent in high latitudes

Fig. 7.4: Glacier Types.

glacier ice is a crystalline solid that can be deformed, the transfer of ice from the accumulation zone to the ablation zone takes place partly by basal sliding (about 50%) and partly by internal deformation (about 50%) of the ice mass by various processes. The flowing glacier usually consists of a series of segments where the ice is moving rapidly as if the ice was being stretched and others where the ice is moving slowly as if the ice was being compressed. This flow pattern is referred to as extending and compressive flow.

The speed of ice movement depends on many factors of which some of the most important are temperature of the ice, slope of the ice surface, and presence of meltwater. As temperatures in Tasmania even during glaci-ation were not extremely cold, slopes were generally steep, and meltwater was abundant, iceflow would have been rapid, and the ice would have been transferred from the accumulation to ablation zones within a few centuries.

Below the firnline the ice flow decreases in velocity, and ablation causes more snow and ice to be removed from the glacier surface by summer melting than is added in winter. The ablation zone, therefore, has a negative budget. As the rate of ice movement decreases near the terminus, the ice generally tends to move upwards towards the surface. In doing so, it may bring basal debris to the ice surface along upward-curving thrust planes (Fig. 7.3).

If accumulation exceeds ablation for the whole glacier for some time, then the snout of the glacier is likely to advance. But, if ablation exceeds accumulation for a decade then the glacier terminus is likely to retreat. Major variations in climate will cause the general advance and decay of a glacier, accompanied by a series of lesser stages of advance and retreat that take place due to short-term oscillations of climate.

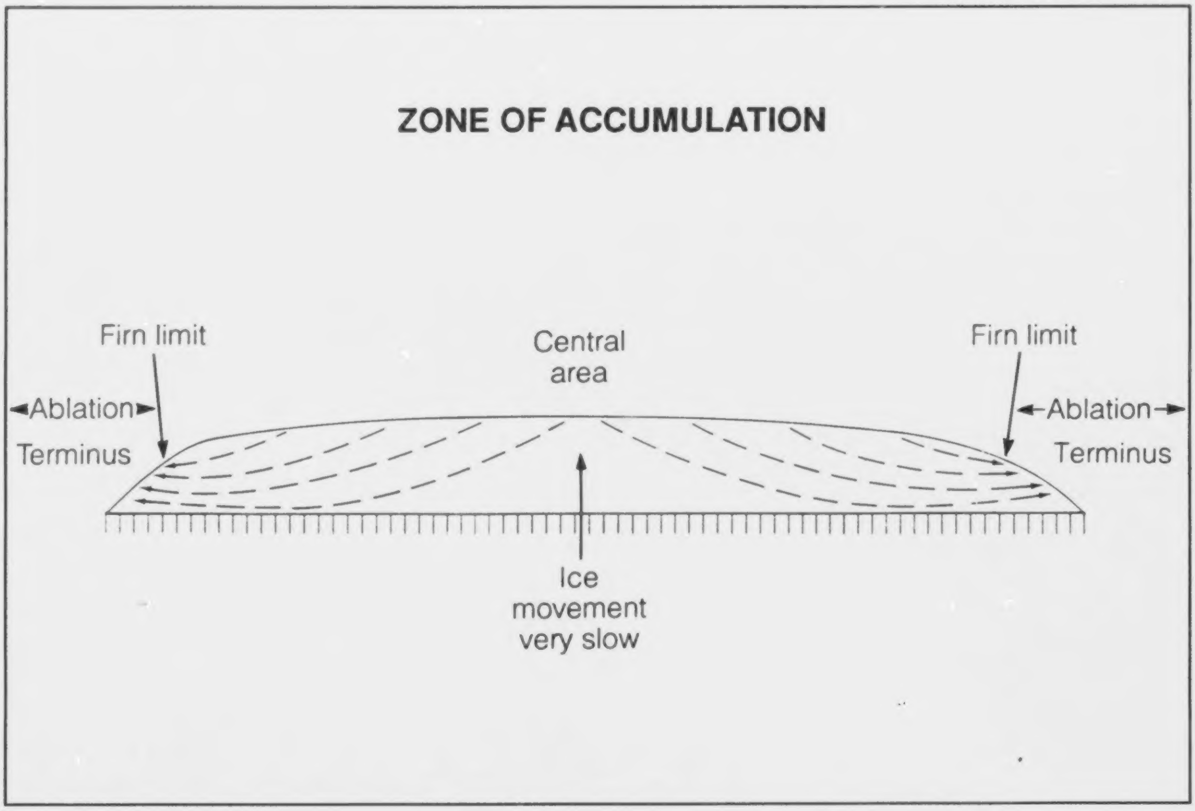
The former glaciers of Tasmania were all of the temperate type, and included cirque, valley, ice cap, outlet and piedmont glaciers. They were the product of cold climate conditions in a mountainous environment in which the pre-existing landforms were largely fashioned by the operation of slope and fluvial processes on a complex geological structure. The effects of glaciation were largely to retouch and modify the existing landscape by creating minor landforms of glacial erosion and deposition. But, glaciation did not create the major landforms of the main river valleys, mountain ranges and plateaux which have a much more ancient history.

By contrast, the environments that formed and maintained the polar ice sheets of Antarctica and Greenland were much colder than the former glacial environments of Tasmania. Similarly, the major ice sheets that formed in North America and Northwest Europe during several stages of the Quaternary were associated with cold, more continental environments than prevailed in Tasmania. Unlike the topographically constrained ice flows of mountainous Tasmania, these thick ice sheets were largely independent of the underlying topography (Fig. 7.4) and the flow was radially outwards towards their peripheries (Fig. 7.5). Because the ice temperatures were colder, the rates of ice movement would have been slower than for Tasmanian ice. Most movement would have occurred by internal deformation with only limited basal sliding of the ice.

Since the Antarctic and Greenland ice sheets have been present from pre-Quaternary times, and since the accumulation of ice in mountains accounted for only a small amount of the earth's total ice at any time, it was the formation and decay of the North American and Northwest European ice sheets that primarily controlled the falls and rises of sea level during each glacial and interglacial stage. Though the cause was largely external, these world wide glacio-eustatic falls of sea level to -130m influenced Tasmania. They not only drained Bass Strait but also caused the main rivers like the Derwent, Gordon and Pieman to erode deep rock channels to well below modern sea level in their estuarine reaches. The buried channel of the Derwent becomes deeper downstream from -6m at New Norfolk, -29m at Bridgewater, -49m at Bowen Bridge, to -85m at the Tasman Bridge (Colhoun, 1983; Colhoun and Moon, 1984.)

The large polar ice sheets and former northern hemisphere ice sheets contained sufficient ice mass to cause the crust of the earth to be depressed isostatically by their weight. The continental shelf of Antarctica is at more than twice the depth of other continental shelves (i.e. 500m rather than 200m), and northern North America and Europe are recovering from being depressed by the last glaciation ice sheets. Through the process of glacio-isostatic uplift Hudson Bay in Canada and the Gulf of Bothnia between Sweden and Finland will both eventually be drained of sea water. For an area to be affected by such glacio-isostatic depression and uplift, an ice sheet of considerable proportions has to have been present for several millenia. In Tasmania the total mass of ice appears to have been too small during any period of glaciation to have caused any detectable depression and isostatic response of the earth's crust.

Fig. 7.5: Cross-section of a typical ice-sheet.



Landforms of glacial erosion

In all regions of mountain glaciation a broad distinction can be made between the zone where glacier erosion predominates and that where glacier deposition occurs. Most of the large erosional landforms are best developed in the upper two thirds of the glaciers' course above the equilibrium line, whereas most of the depositional forms are associated with the slower moving ice of the lower third of the glacier below the equilibrium line. Clearly, the position of the glacier equilibrium line will change with respect to the underlying landscape during glacier advance and retreat, and it is during the latter phase that most deposition occurs. Accordingly, in any landscape, it is possible to find some signs of glacier erosion within the zone of predominant deposition, and some glacial deposits in the zone of former intense glacier erosion.

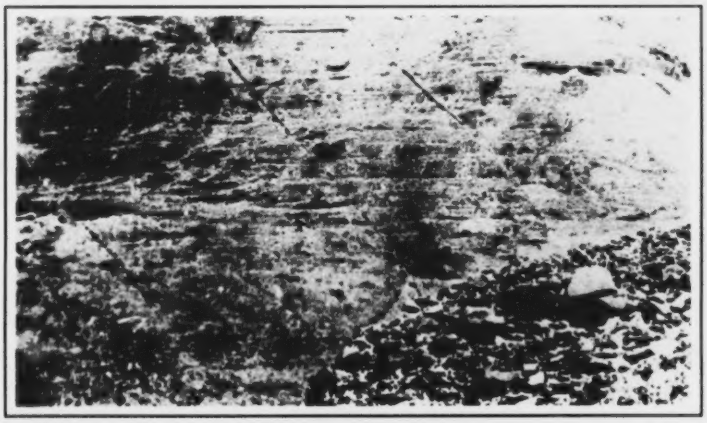
Landforms produced mainly by the processes of glacier erosion can be divided into large scale and small scale forms. The large scale forms include cirques, glacially modified valleys, hanging valleys, glacial diffluence cols, knock and lochan landscapes, and to some extent nunatak peaks. The small scale forms include glacial polishing, scratching and gouging of rock surfaces, formation of roches moutonnées, and to some extent the production of erratics.

The two processes that fashion most of these forms are glacial abrasion and quarrying which is sometimes called plucking. Since ice is physically softer than most rocks and will flow under pressure, it can effect very little erosion unless it is armed with a load of debris. Such rock detritus is initially acquired by removal of the pre-existing soil from the landscape. Once this is frozen into the base of the ice it acts like a huge file or sheet of sandpaper as it moves over the landscape wearing it away. It scrapes clean, abrades, scratches and polishes the underlying rock.

In addition, in areas where the rock is strongly jointed, cleaved or fractured, the ice in the cracks will be connected with the basal ice of the glacier which, as it moves on, may quarry or pluck the block or fragment of bedrock from its original position and incorporate it within the load of the glacier.

The mountains of western Tasmania contain many cirque basins that were eroded by ice at the glacier sources. Some of the cirques only contained cirque glaciers (Fig. 7.7), while others connected with valley glaciers. The deepest cirques occur either in areas of resistant rocks or leeward of large pre-existing scarps. They are characterised by steep glacially-eroded headwalls 100 – 300m high, deep concave rock basins that frequently contain a tarn, and rock bars or moraine ridges that separate them from the glaciated valleys. Good examples include Lake Rhona cirque in the Denison Range, Lake Huntley cirque in the Tyndall Range, the Swallows Nest in the Mount La Perouse area, and Lake Wilks which occupies a rock shelf 130m above Lake Dove in Cradle Mountain National Park.

Fig. 7.6: An ice-scratched surface, Rosebery.



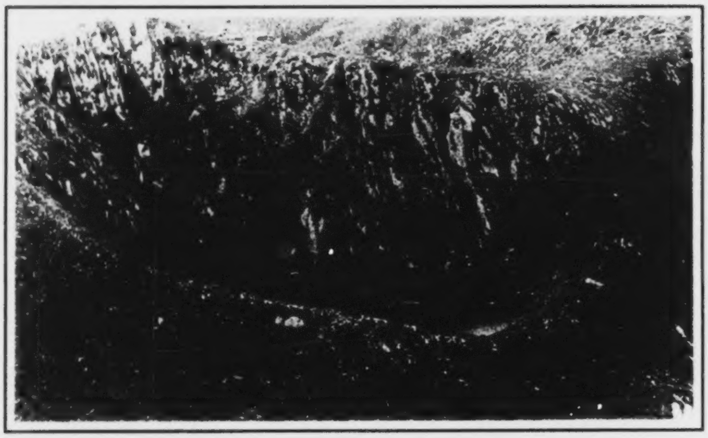


Fig. 7.7: Diamond Lake, Denison Ranges: a tarn lake in a cirque.

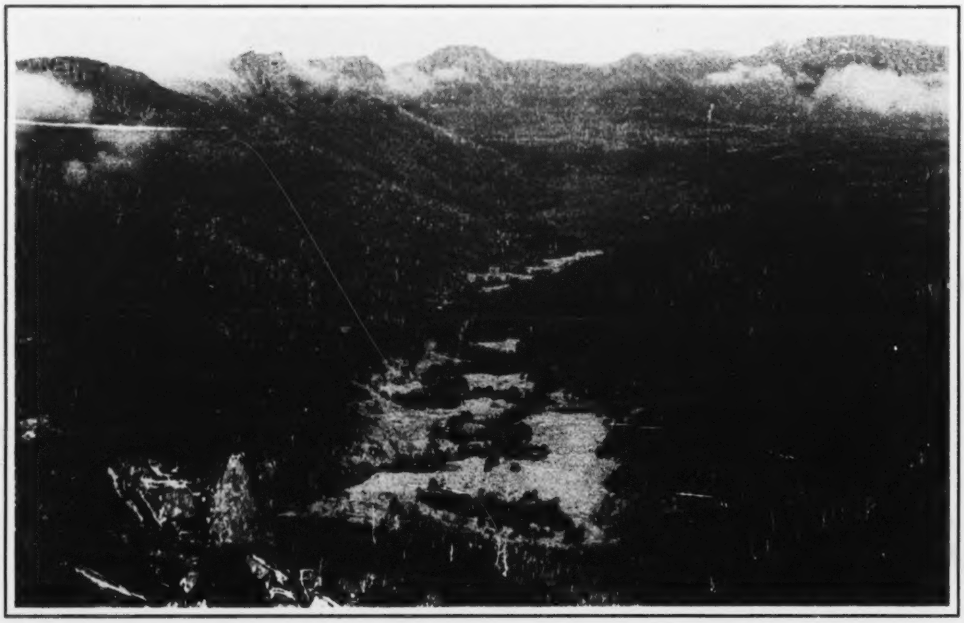


Fig. 7.8: Lees Paddocks in the Upper Mersey Valley, enlarged to a U-shape by the passage of ice.

Where valley and outlet glaciers flowed downhill through existing valleys they frequently modified their forms substantially. The glaciers eroded the valley walls, truncated protruding spurs, and differentially deepened the valley floors. After deglaciation the cross-profiles were more U-shaped than before glaciation, the truncated spurs had the shape of flat-irons, tributary valleys were left hanging above the deepened main valley floors which contained ribbon lakes in their deepest sections. The upper Mersey Valley (Fig. 7.8) has been considerably modified by glacial erosion and has more of a U-shape than it had previously. Because of the glacial deepening along Chapter Lake and Moses Creek a tributary valley has been left hanging some 60m on the eastern side to create Grail Falls. Lake St. Clair is 168m deep and is the deepest lake in Australia. It is a good witness of the intensity and differential nature of glacial erosion (Derbyshire, 1971).

Occasionally a valley glacier will be sufficiently thick almost to fill the main valley and may overtop a col or low divide between adjacent valleys. The power of the ice is usually sufficient to erode the col to a lower level and alter its form from a V-shape towards a U-shape. Such a diffluent glacier is exemplified by the overspill of ice that occurred north of Mount Olympus, where ice from the Hamilton Creek Valley flowed southwards through Byron Gap into the Cuvier Valley.

At its upper limits the eroding ice may flow around mountain summits that protrude above the ice surface. In doing so, the ice usually produces a distinct boundary between the rounded masses of glaciated rocks that are free of surface debris below the ice limit and the jagged summit and upper slopes of the protruding nunatak which are mantled with frost produced scree above the ice limit. Cradle Mountain, and Mount Rogoona in the Walls of Jerusalem area, are good examples of nunataks.

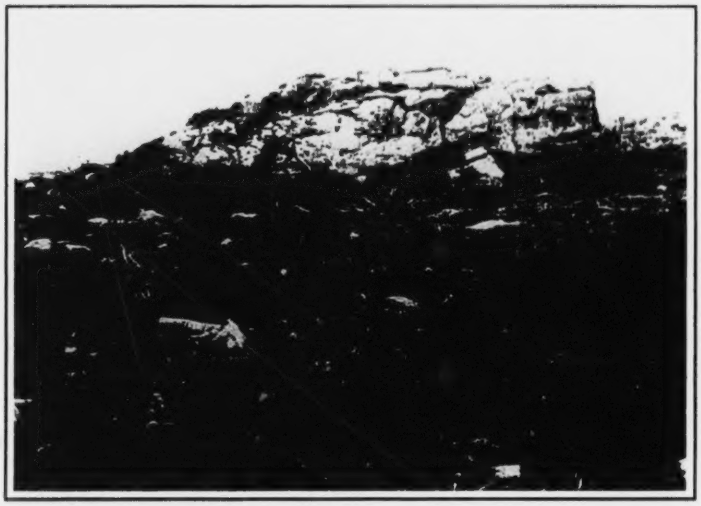


Fig. 7.9: Roche moutonnée in Jurassic dolerite, Hartz Mountains. View looking west. Note smoothed northern side and plucked southern side showing ice movement from north to south.

Where rapidly flowing ice moves across resistant bedrock that has very little overlying weathered material it cuts large scratches, called striations, and grooves into the rock, and polishes the surfaces. These forms indicate the direction of glacier movement. Where rocks are strongly jointed or cleaved the outcrop may be strongly ice moulded and abraded on its upstream or stoss side and strongly quarried on its downstream, (Fig. 7.9), or lee side to give the distinctive form known as a roche moutonnée. Such forms are common on the Lake Dora Plateau of the West Coast Range and on the western part of the Central Plateau around Chalice Lake (Fig. 7.10). Both these areas were extensively eroded by ice which produced a landscape of low rock hills that are separated by ice-scoured rock basins, many with lakes that are aligned along major joints. Where either extensive lowland plains or upland plateaux were severely eroded to produce thousands of small rounded hills separated by small lakes in ice-scoured basins, Linton (1964) referred to them as knock and lochan landscapes after areas of this character in the Highlands of Scotland.

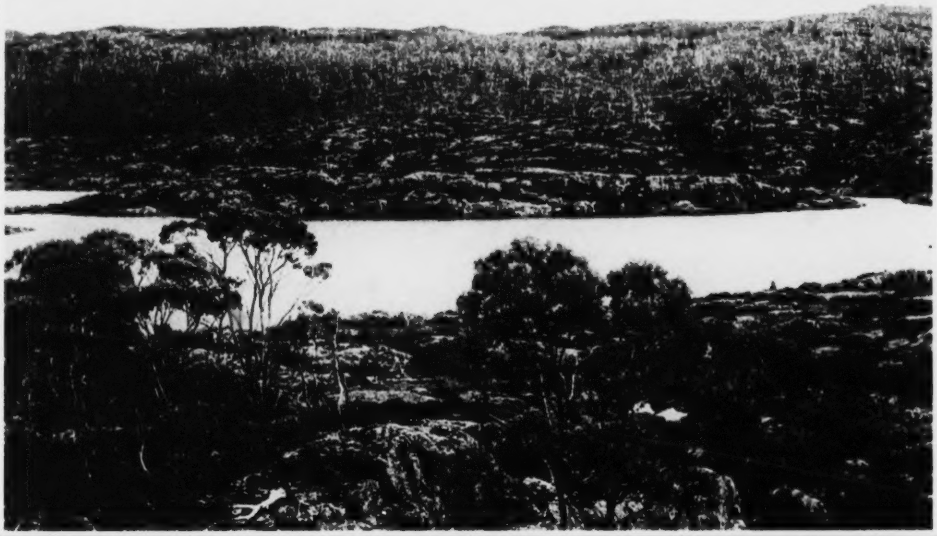


Fig. 7.10: Chalice Lake on Central Plateau showing knock and lochan type landscape.

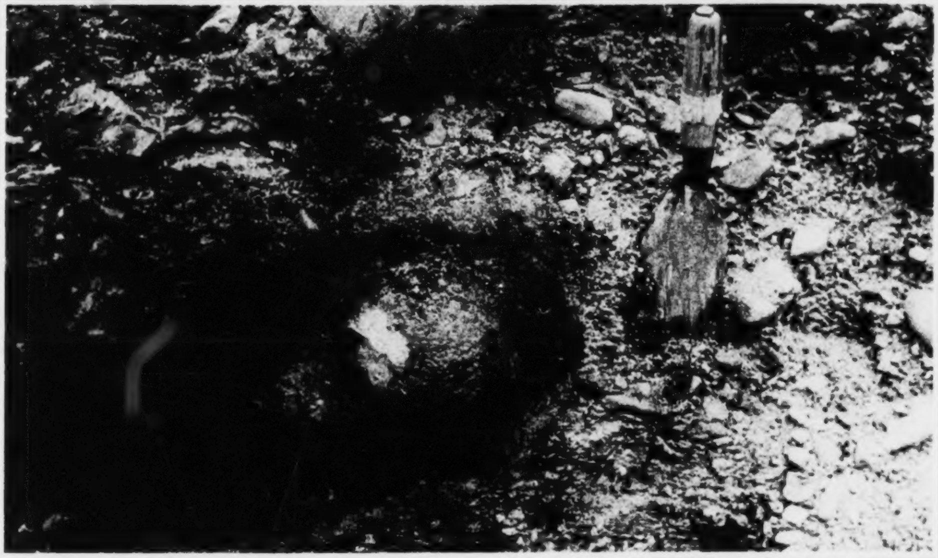


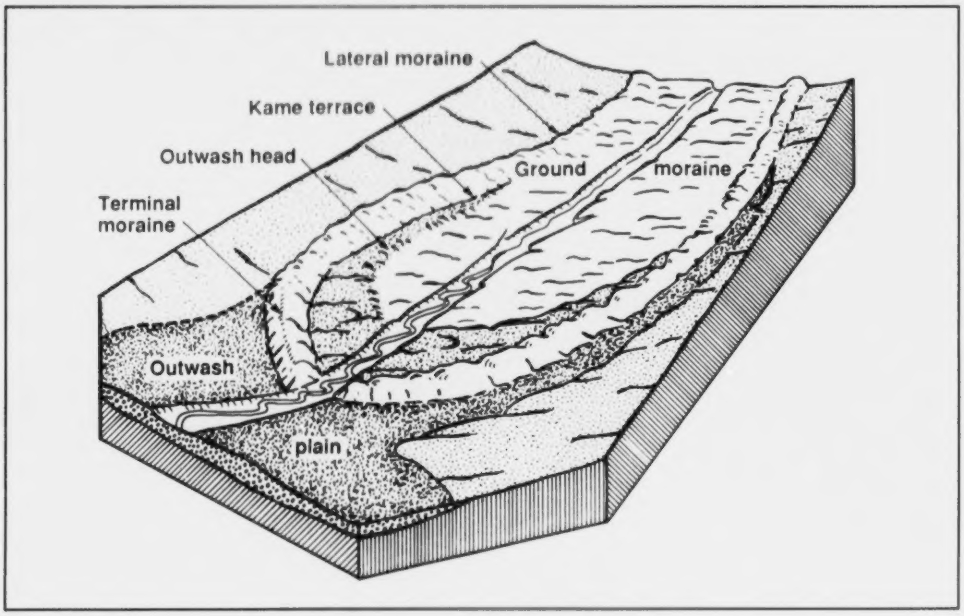
Fig. 7.11: Deeply weathered dolerite boulder in moraine at Mount Lyell mine.

The process of quarrying often detaches large joint-bounded masses of rock which may be carried for long distances and deposited at a site where the underlying rock is different from the ice-transported boulder. Such erratics are common in areas of glacial deposition, and study of their lithology and provenance may help with the reconstruction of patterns of ice flow in a region. In western Tasmania, Jurassic dolerite erratics from the Mount Eldon area were transported southwards into the King Valley, and westwards into the Comstock and Linda Valleys. These erratics were also transported through gaps in the West Coast Range to the Queen Valley where they can be found in moraines around Queenstown (Fig. 7.11). Similarly, erratics of Owen Conglomerate from the Tyndall Mountains were transported westwards across the Henty Peneplain to the Loftus Hills Memorial at the limit of glaciation 8 km north west of Queenstown.

Glacial deposits and associated landforms

Beyond the zone of glacial erosion occurs the zone where deposition is predominant. This zone occurs below the equilibrium line, near the glacier terminus and in the proglacial zone beyond the ice limits (Fig. 7.12). Here deposits, collectively referred to as glacial drift, are laid down by ice and its meltwaters. The deposits do not occur everywhere but generally mantle the floors of valleys and the lower slopes of hills. Glacial drifts are classified (Fig. 7.13) into unstratified drifts in which meltwater plays little part in their sedimentation and stratified drifts in which deposition is associated with an abundance of meltwater.

Fig. 7.12: Depositional landforms and deposits usually associated with a valley glacier.



Unstratified Drift	Stratified Drift
Flow-till	Glacimarine deposits
Ablation till	Glaciolacustrine deposits
Meltout till	Glaciofluvial or outwash deposits
Basal or lodgment till, or ground moraine	Ice-contact deposits
Deformation till	

Fig. 7.13: Types of Glacial Drift.

These deposits can be considered to form in one of three main environments.

- the glacial environment of ice ablation
- the ice-contact zone at the limits of glaciation
- the proglacial environment where meltwater streams deposit sediments on broad streambeds, in lakes, or in the sea.

Each deposit has certain distinguishing characteristics and some are associated with distinctive landforms.

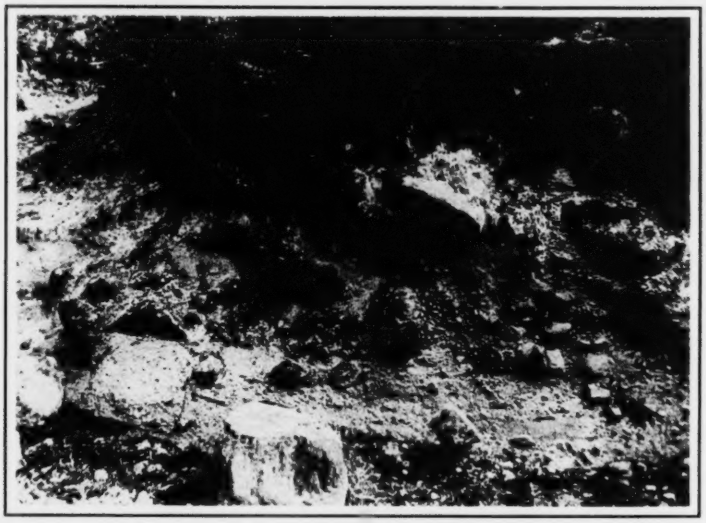


Fig. 7.14: Till deposits derived from Jurassic dolerite at Lake St.Clair (Last Glaciation age).

The glacial environment is characterised by the deposition of largely unstratified till deposits. These represent the former load of the glacier and consist of variably-sized boulders and cobbles set in a matrix of sand, silt and clay-sized particles. They are generally unbedded, poorly-sorted, and contain a mixture of local rock types with a few far-travelled erratics. Typically glaciated cobbles have striated (scratched) surfaces and flat-iron faces.

Close to the bedrock surface a deposit of broken angular rock fragments with little matrix may occur locally. Such deformation till results from the fracturing of rock by moving ice which shears over the surface and sometimes produces fold and shear structures within the deposit. A deformation till can be observed at Horeb Falls on Moses Creek in the Mersey Valley area.

The greatest volume and most extensive deposits are usually formed at the base of the ice as basal or lodgement till. These tills mantle the floors and slopes of glaciated valleys, are very compact, and contain ice-scratched cobbles and boulders set in a sand to clay matrix (Fig. 7.14). Elongated cobbles tend to be oriented in the direction of former ice movement. Where extensive and thick basal till deposits occur they may form undulating till plains, some of which may be characterised by the oval-shaped hills called drumlins in Ireland, or by corrugated areas of fluted-drift as occurs in a small area north of Lake Rolleston in Western Tasmania. However, most basal till in Tasmania occurs as sheets on the valley floors behind large end moraines, as at Lake St. Clair and at Lake Margaret Village where the moraines mark the last glaciation ice limits (Fig. 7.15).

As the glaciers decay the detritus transported in and on the ice is gradually lowered to the ground where it is deposited. The detritus within the ice mainly produces meltout till while the detritus on top of the ice mainly produces ablation till. Meltout till is less compact than basal till, frequently shows weak bedding structures, and may contain thin laminae of sand or lenses of small gravel produced by limited water sorting during deposition. Areas of meltout till deposits were exposed in the Mackintosh Valley during dam construction work.

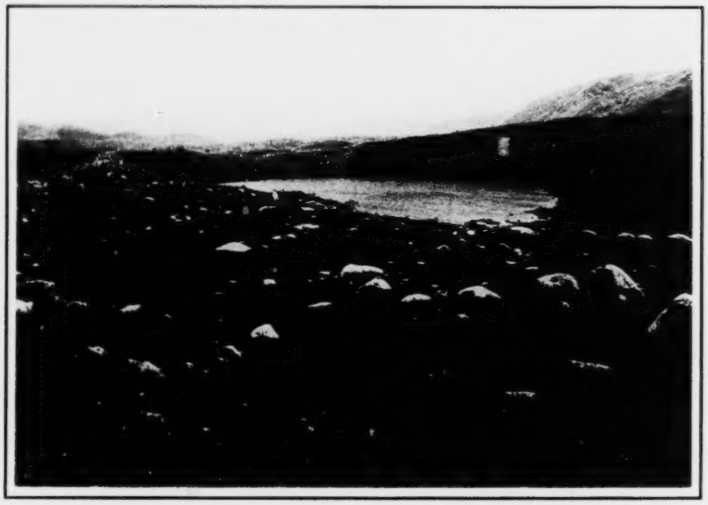


Fig. 7.15: Hamilton End Moraine and Basin Lake, West Coast Range.

Ablation till is lowered from the ice surface and consists of coarse angular debris with little matrix. It is usually discontinuous and frequently characterises the surface deposits of lateral moraines next to steep slopes.

At the snout of a glacier, or within the zone of ablation, detritus that has accumulated on an ice surface, or has already been deposited beneath the ice, may become saturated with water and flow downslope on ice, rock or till surfaces to be deposited in a manner similar to a mudflow. Such flow-tills are usually restricted in extent, but may form multiple thin sheets of till-like material interbedded with washed sands or laminated clays.

Much deposition occurs next to the sides of glaciers and in the zone at the end of the glacier. Because of short-term advances and retreats of the ice front, and occasional stagnation of ice masses, these deposits can be pushed by active ice or collapse over the melting out of buried dead ice. Such processes, therefore, give a mixed group of deposits, laid down in contact with ice, that vary rapidly both vertically and laterally. The deposits may include masses of basal till, beds of flow-till, wedges of ablation till, thick beds of coarse gravel, beds of well-washed sand and rhythmites of silt and clay. All may be interbedded, and faulted and folded due to ice-pushing, ice collapse, ice loading, and flowage of saturated sediment. Typically such sediments with their associated structures are found in lateral and end moraines, in ridges called eskers deposited by streams flowing beneath glaciers, and kames and kame terraces which occur where the deposits are laid down in pools of water either within the ice or between the ice margin and the hillslope.

The impressive Hamilton and Lake St. Clair end moraines have already been mentioned, and a distinctive lateral moraine that descends in altitude down-valley along the ice margin occurs in Mount Field National Park on the eastern valley slope above Lake Belcher. Examples of esker ridges and kame terraces are rare in Tasmania, though a small esker occurs north of Lake St. Clair and a distinct flat-topped kame terrace occurs on the northern side of the Mackintosh Valley adjacent to the Murchison Highway.

Cirque moraines usually form in the ice contact zone either during the final stages of glacial retreat or at the limits of cirque glaciers. They tend to be composed of a mixture of till and boulders with little matrix. The moraine at Lake Dobson is a cirque moraine formed during a retreat or readvance phase that succeeded the maximum of the last glaciation.

Beyond the snout of the glacier and the end moraine the meltwater will spread out over the valley floor in a series of many dividing and converging channels which are called braids. These streams of meltwater are heavily charged with sediment and deposit it on the valley floor or plain roughly in the order of decreasing grain size. Thus, coarse outwash gravels will generally be closer to the ice limits than fine outwash sands. As the ice front retreats further up valley, the braided channels may coalesce into a main channel and the outwash deposits may be incised to produce pairs of outwash terraces on either side of the valley. Outwash deposits are usually moderately sorted, and may show the casts of former braided channels.

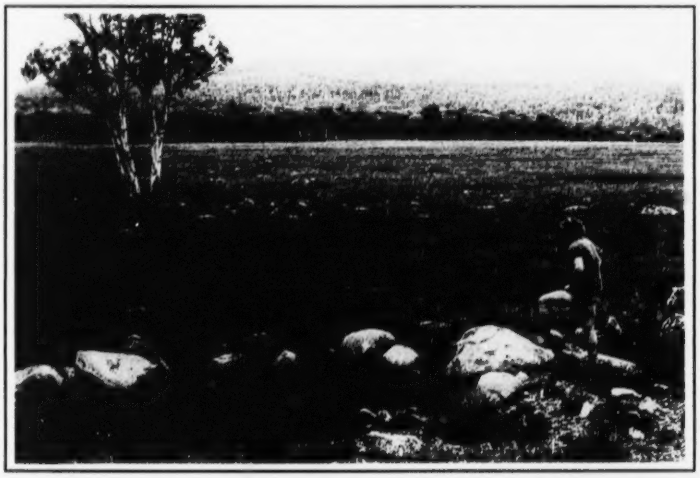


Fig.7.16: Outwash plain 5km west of Derwent Bridge.

An extensive outwash terrace extends from below Rowallan Dam in the Mersey Valley for 2 km down valley and was produced when the Mersey glacier attained its limit during the last glaciation. Extensive outwash plains also occur in the area between Derwent Bridge and Lake St. Clair (Fig. 7.16).

The finer products of glacial erosion, the rock flour consisting of silt and clay-sized particles, are either deposited in small lakes within the decaying ice or are carried in suspension by the meltwaters into lakes in outwash plains. In both cases the glaciolacustrine deposits usually consist of laminated silts and clays, like cheese slices, with occasional cobbles that were dropped by the melting of floating ice. Sometimes the laminations are observed to consist of a gradation from silt to clay with a sharp upper boundary to the clay. Such rhythmites are frequently termed varved deposits. They are thought to represent an annual cycle of spring-summer melt when the silt is deposited, and winter freezing of the lake when the clay in suspension settles to the bottom. At Gormanston in western Tasmania a thick sequence of glaciolacustrine rhythmites can be seen in association with basal till and flow-tills where ice from the King Valley dammed up a small lake at the head of the Linda Valley (Fig. 7.17).

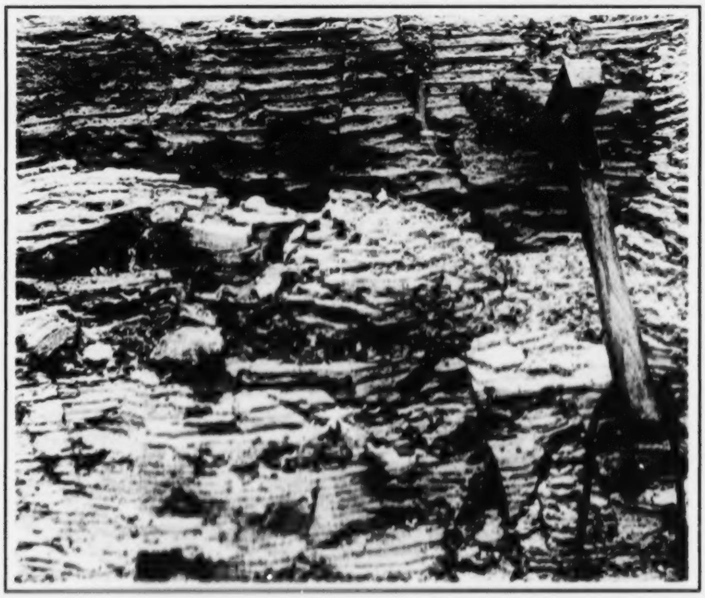


Fig. 7.17: Laminated silts and clays with glacial drop stones at Gormanston, Western Tasmania.

Where glaciers or ice sheets terminate in the sea most of the debris will melt out from the base of the ice to produce glaciomarine deposits. These are usually poorly to moderately bedded and have variable sedimentary characteristics which may resemble those of till, flow-till or glaciolacustrine sediments. However, many glaciomarine deposits contain shells and microfauna, especially where extensive ice shelves occurred. There are no Quaternary glaciomarine deposits in Tasmania but such deposits are well known from the early Permian glaciation of Tasmania and southern Australia.

Quaternary multiple glaciations

Unlike Antarctica which has probably been continuously glaciated for at least 10 million years, the middle latitude regions of both the Northern and Southern Hemispheres have experienced the waxing and waning of several glaciations of much shorter duration during the 1.8 million years of the Quaternary.

Knowledge of the number and character of the Quaternary glaciations of Tasmania has increased greatly during the last decade particularly as the result of studies in the West Coast Range and in the Mersey Valley. Summaries of these studies illustrate that Tasmania had a complex multi-glacial history. During cold climate stages glaciers and ice caps formed on the mountains of central and western Tasmania, while during the warmer climatic interglacial stages the landscape was extensively forested as it is today. The results have been obtained by mapping the landforms and deposits, radiocarbon dating organic deposits, studying the weathering of rock clasts in the deposits and by analysis of pollen from organic sediments (Derbyshire, 1972; Colhoun, 1979, 1985; Kiernan, 1983; Augustinus and Colhoun, 1986; Hannan and Colhoun, 1987).

Western Tasmania

The region west of the King Valley that extends from Mount Sorell in the south to the Bulgobac Valley in the north has been glaciated at least three times during the Quaternary. The glaciations were centred on the Tyndall Mountains and the Lake Dora Plateau to the east where ice caps were formed, and from which valley glaciers radiated outwards into the adjacent valleys (Fig. 7.18).

The Margaret Glaciation

The last glaciation culminated ca. 18,800 years ago and is called the **Margaret Glaciation** from the impressively glaciated area west of Lake Margaret that is bounded by the Hamilton End Moraine. Being younger than 130,000 years old the Margaret Glaciation is of Late Pleistocene age. During this glaciation the regional snowline occurred at ca. 830m which is 1000m lower than it would be today. This represents an annual average decrease in temperature of 6.5°C from present. The colder climate endured sufficiently long for over 100 km^2 of terrain to be blanketed by the West Coast ice cap and its outlet glaciers, and for cirque glaciers to form leeward of the highest mountain peaks in the Murchison Range and in the southern part of the West Coast Range from Mount Owen to Mount Sorell. The ice varied in thickness from 100 - 250m. The chief effects of this ice were to erode the summits of the Tyndall Range and the Lake Dora Plateau. Here, most of the soil has been removed and the rock has been heavily ice-scoured. The debris has been piled up in the large end moraines north of Lake Rolleston, at the exit of the Tyndall Valley, west of Lake Margaret and on the northern slopes of the Comstock Valley. These largely undissected till and ice-contact morainic deposits have only been very weakly weathered with soil profiles not extending to more than 50cm depth, and dolerite clasts showing chemical weathering skins of under 1mm in thickness.

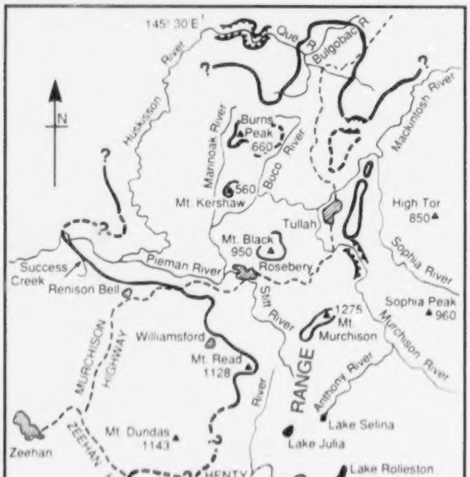

145° 30'E
N
Que R
Bulgobac R
Huskisson River
Marinoak River
Burns Peak 660
Boco River
Mackintosh River
560
Mt. Kershaw
High Tor 850
Tullah
Mt. Black 950
Success Creek
Pieman River
Rosebery
Renison Bell
Sophia River
Sophia Peak 960
Stitt River
1275 Mt. Murchison
Murchison River
MURCHISON HIGHWAY
Williamsford
Mt. Read 1128
River
RANGE
Anthony River
Lake Selina
Zeehan
Mt. Dundas 1143
ZEEHAN HIGHWAY
Lake Julia
HENTY SURFACE
Lake Rolleston
1158 Mt. Tyndal
Lake Dora
River
Henty
Langdon River
Mt. Glekie 1100
Eldon Peak 1439
Lake Margaret
Mt. Sedgwick 1147
Eldon River
South Eldon River
42°S
River
Yolande
COAST
Comstock River
Henty River
Mt. Lyell 920
Linda R.
Gormanston
Princess R
LYELL HWY
Queenstown
1146 Mt. Owen
Queen River
King
Nelson R
LYELL HIGHWAY
Mt. Huxley 925
Strahan
Mt. Jukes 1168
Governor R
King River
Pyramid Peak 1080
WEST
Mt. Darwin 1031
Andrew River
Mt. Sorell 1144
Maximum known extent of ice in western Tasmania
Gorge
0 5 10
Kilometres

Fig. 7.18: Map showing the maximum extent of late Cainozoic ice in western Tasmania.

The Henty Glaciation

The preceding glaciation termed the **Henty Glaciation** is known to be more than 43,800 years old by radiocarbon dating, but it is thought that it may have preceded the last interglacial period in age and be over 130,000 years old. If so, the Henty Glaciation is probably of Middle Pleistocene age. During the Henty Glaciation the ice was about ten times more extensive than during the Margaret Glaciation and covered over 1000 km^2. The ice cap on the West Coast Range was thicker and the outlet glaciers extended much further down the adjacent valleys than during the Margaret Glaciation. Though the ice attained thicknesses of 300 to 400m and the outlet glaciers were up to 20 km in length, the annual temperature depression estimated at ca. 7°C and the regional snowline at ca. 740m altitude were only slightly greater than for the Margaret Glaciation.

The deposits associated with the Henty Glaciation have been slightly more dissected by subsequent stream erosion and are slightly more chemically weathered than the Margaret Glaciation deposits. The weathering has formed soil profiles to about 1m depth and has formed rinds of 1 - 22mm thickness on dolerite clasts in the morainic deposits. In the Boco Valley in the northern part of the region, it has been suggested that two glaciations of Henty age occurred between the youngest Margaret Glaciation and the older **Linda Glaciation**. There are also indications in the King Valley that the equivalent deposits of the Henty Glaciation, referred to as the Comstock, may represent more than one glaciation. However, such indications need to be substantiated further before regional subdivision of the Henty glacial drifts can be made.

The Linda Glaciation

The Linda Glaciation is known to be more than 700,000 years old because magnetic minerals in the associated glaciolacustrine deposits have reversed (southern) polarity rather than a normal (northern) polarity (Barbetti and Colhoun, 1988). This proves at least an Early Pleistocene age and does not preclude a late Tertiary age for this earliest and most extensive glaciation of western Tasmania. The extent of the glacial deposits is locally slightly greater than for the Henty Glaciation deposits, especially in the Linda and Pieman Valleys. Thus, the area covered by this ice was only slightly greater than during the Henty Glaciation; and the snowline altitude and temperature depression values were probably very similar. Because of the great age of the deposits undisturbed overlying soil profiles are frequently 2 – 3m deep, and dolerite clasts within the deposits have weathering rinds that vary from 20 to 300mm in thickness. Other chemically weatherable igneous rock clasts are also intensely altered, and the deposits have multiple and thick iron-pans throughout.

At Linda Creek the glacial deposits terminate adjacent to alluvial sands and gravels which contain a fossil soil with abundant pollen grains that are of Tertiary type. The soil represents a preglacial landsurface and together with the alluvial deposits is probably of Pliocene age (Fig. 7.19).

The preceding description allows us to conclude that western Tasmania was glaciated on at least three, possibly four, occasions in the late Cainozoic (i.e. Quaternary and late Tertiary).

Fig. 7.19:
Alluvial sands and gravels overlying a fossil soil containing pollen of Tertiary-type at Linda Creek.

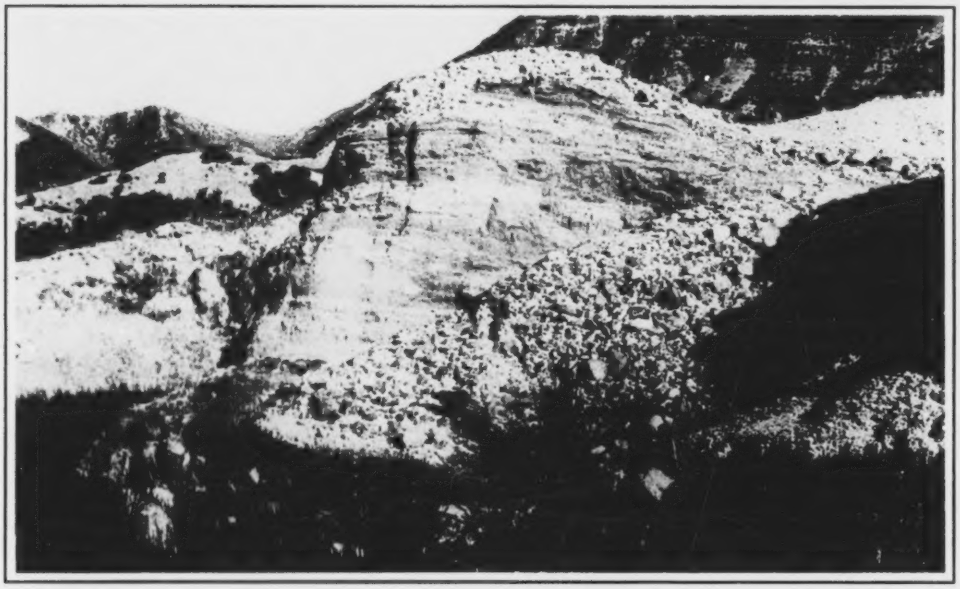


Fig. 7.20: Glaciations of Western Tasmania - The West Coast Ranges.

Late Pleistocene	Last Glaciation or Margaret Glaciation	Maximum 18,800 years BP (before present); probable duration of ice 26,000 - 14,000 years BP
Middle Pleistocene	Penultimate Glaciation or Henty Glaciation	More than 43,800 years BP; probably more than 130,000 years BP. Also probably more than one glaciation represented
Early Pleistocene or Late Tertiary	Earliest Glaciation or Linda Glaciation	More than 700,000 years old

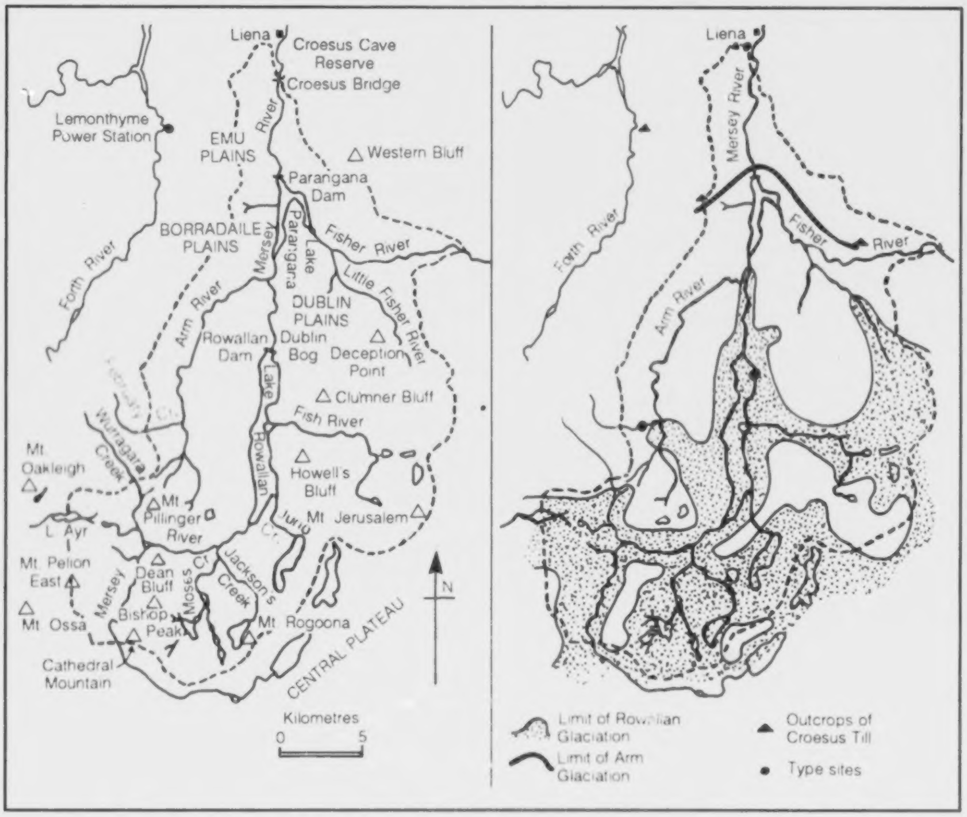

Liena
Croesus Cave Reserve
Croesus Bridge
Lemonthyme Power Station
EMU PLAINS
Mersey River
Western Bluff
Parangana Dam
BORRADAILE PLAINS
Lake Parangana
Fisher River
Forth River
Arm River
Little Fisher River
DUBLIN PLAINS
Rowallan Dam
Dublin Bog
Deception Point
Clumner Bluff
Fish River
Lake Rowallan
Mt Oakleigh
Wurragara Creek
Howell's Bluff
Mt Pillinger
Mt Jerusalem
Juno Cr.
L. Ayr
River
Mt. Pelion East
Dean Bluff
Moses Cr
Jacksons Creek
Mt Ossa
Bishop Peak
Mt Rogoona
CENTRAL PLATEAU
Cathedral Mountain
N
Kilometres
0
5
Liena
Mersey River
Forth River
Fisher River
Arm River
Limit of Rowallan Glaciation
Limit of Arm Glaciation
Outcrops of Croesus Till
Type sites

Fig. 7.21: Glaciation of the Mersey Valley.

The Mersey Valley

Glaciation of the Mersey Valley occurred on at least three occasions during the Quaternary Period. On each occasion the main source of ice was the icecap on the northwestern edge of the Central Plateau. Ice flowed down the main valley as well as along some of the western tributaries. The periods of glaciation have been named from youngest to oldest the **Rowallan Glaciation,** the **Arm Glaciation** and the **Croesus Glaciation**. The Rowallan Glaciation had the least and the Croesus Glaciation the most extensive ice cover.

The Rowallan Glaciation

The ice limits of the Rowallan Glaciation are now well established (Fig. 7.21). Ice flowed down the Mersey Valley past the Rowallan Dam and terminated in two tongues. One tongue occupied the main valley and the other Dublin Plains where well developed end moraines were formed. Two small glaciers existed on the western edge of the main glacier. The most southerly occupied the valley of Wurragara Creek to an altitude of 1000m and linked with the Forth River system through Lake Ayr. The other ice tongue pushed over the western edge of the valley into the upper Arm River southwest of Maggs Mountain. On the eastern side, ice flowed from the Central Plateau down Moses Creek, Jacksons Creek and the Fish River to join the Mersey glacier. A small valley glacier pushed down the Little Fisher River to 800m but did not reach the main glacier.

It is likely that most mountain peaks above 1200m in the region protruded above the ice as nunataks. The summits have thick mantles of dolerite boulders such as those that can be seen near the summit of Mount Pillinger.

The Rowallan Glaciation is identifiable by the largely unweathered nature of its basal and meltout till. Dolerite clasts within the till have weathering rinds less than 1mm in thickness.

Radiocarbon dating of lake deposits behind the end moraine at Dublin Plains indicate that the ice limit was attained before 13,400 yr. B.P.

The Arm Glaciation

The Arm Glaciation was more extensive than the Rowallan Glaciation and extended down the Mersey Valley to just below Parangana Dam. The Arm Glaciation extended across most of Borradaile Plain and was connected with the Forth Glacier over a wide front. It is likely that most of the peaks in the district were covered by ice to form a thin plateau ice cap.

The tills of the Rowallan and Arm glaciations may be compared in the upper Arm Valley, where Rowallan till overlies and contains fragments of the Arm till. The Arm till is seen to be considerably more weathered than the Rowallan till and contains dolerite clasts with weathering rinds of 1 to 8mm in thickness.

The Croesus Glaciation

The Croesus Glaciation is indicated by a number of occurrences of very deeply weathered till which crop out in the vicinity of Croesus Cave in the Mersey Valley and at Lemonthyme Power Station in the Forth Valley. In this till the dolerite clasts have weathering rinds that average 51mm in thickness. Since the Croesus deposits occur much further north in the Mersey Valley and are much more weathered than the Arm deposits, it is evident that the Croesus Glaciation was the most extensive and oldest of the three glaciations to affect the area.

The weathering characteristics of dolerite clasts in the tills of the Rowallan, Arm and Croesus glaciations are so different that they suggest separate glaciations separated by long intervals. Comparison with the glaciations of the West Coast Range would suggest late, middle and early Pleistocene ages respectively (Kiernan, 1983; Colhoun, 1985).

Fig. 7.22: Glaciation of Northern Tasmania - The Mersey Valley.

Late Pleistocene	Last Glaciation or Rowallan Glaciation	Maximum occurred prior to 13,400 yr. B.P.
Middle Pleistocene	Penultimate Glaciation or Arm Glaciation	
Early Pleistocene or Late Tertiary	Earliest Glaciation or Croesus Glaciation	Over 700,000 yr. B.P.

Alpine periglacial environments

Areas adjacent to the glaciers and ice sheets experienced cold climates during the Pleistocene. Prolonged freezing of the ground produced widespread permafrost in lowland Eurasia and northern North America. In Tasmania prolonged freezing was confined to a few of the highest mountain areas. On the southern slopes of the Ben Lomond Plateau below Storys Bluff small rock glaciers (Caine, 1983) suggest that limited areas of permafrost were present. Today the alpine regions of Tasmania like Mount Field experience many freeze thaw cycles per annum and the ground surface temperature is below freezing for long periods during winter (Fig. 7.23). However, because of the thick vegetation cover at most altitudes the geomorphic effects of freezing and thawing, like snow erosion, are confined mainly to the sparsely vegetated areas above 1100 to 1200 m.

During the Pleistocene the vegetation cover was reduced and tree-lines were lowered in mountain areas where snow patches combined with strong frost action, which together are characteristic processes of maritime periglacial environments, caused strong erosion of surface materials from upland summit areas and steep slopes. The eroded materials were transported downslope and were deposited on the lower slopes and in adjacent valleys, particularly in the region above 450m. The processes of snow erosion,

Percentage time below 0°C on surface in 1983-84 at 1400m on Mt. Field West

J	F	M	A	M	J	J	A	S	O	N	D	
0	0	0	2	13	46	94	53	49	16	17	0	Aug. and Sept. mean of two records

Monthly mean maximum and minimum surface temperatures

J	F	M	A	M	J	J	A	S	O	N	D	
-0.6	-2.6		-1.6	-4.0	-4.5	-7.3	-6.3	-7.8	-4.5	-4.5	-3.0	Aug. and Sept. mean of two records.
18.7	24.7		23.7	15.7	9.7	9.2	10.7	15.0	18.2	21.2	26.2	Feb. and March values combined.

Fig. 7.23: Annual freeze-thaw cycle, Mount Field West.

called **nivation**, and of frost action produced many minor landforms and deposits, only a few of which can be indicated here.

Beyond the glaciated area snow may accumulate as snow-banks in shaded valley heads but not become thick enough to form cirque glaciers. Instead, the perennial snowbanks may creep gradually downslope and melt at their base and lower margin. With time the snow-creep can erode a hollow into the rock, termed a nivation cirque, and the meltwater can transport the debris away from the lower margin of the snowbanks. A shallow nivation cirque, characterised by a snowpatch vegetation community, occurs at 1220m on the northeastern slope of Mount Campbell, west of Lake Dove and nivation erosion of Precambrian quartzite is currently active in the Mount Anne area (Fig. 7.24).

With the advent of cold climate processes, the effects of strong frost action are first to strip-off and transport downslope any previously chemically weathered soil materials and then to fracture the bedrock along joint planes and minor structural weaknesses. This results in the production of solifluction deposits, block fields and block streams.

In Tasmania most of the solifluction deposits occur above 450m altitude and are best developed on the slopes adjacent to the plateaux of Jurassic dolerite. The deposits consist of rather massive, yellow-brown, bouldery, clay deposits that often overlie strongly chemically altered dolerite. In places the solifluction deposits have thin fossil soil horizons between successive beds. The soils are rarely more than 0.5m thick, but the solifluction deposits may be in excess of 10m. The structured character of solifluction deposits can be seen in sections at 900m altitude at Monpeelyata Canal where the upper 1 to 1.5m of deposit are between 10,000 and 30,000 years old, the middle deposits from about 1.5 to 5m are from about 30,000 to 100,000 years old, and the lowest deposits below a thick soil profile are probably more than 130,000 years old (Fig. 7.25). Thus, thick solifluction deposits take considerable time to accumulate, develop episodically when the landscape surface is unstable, and belong to more

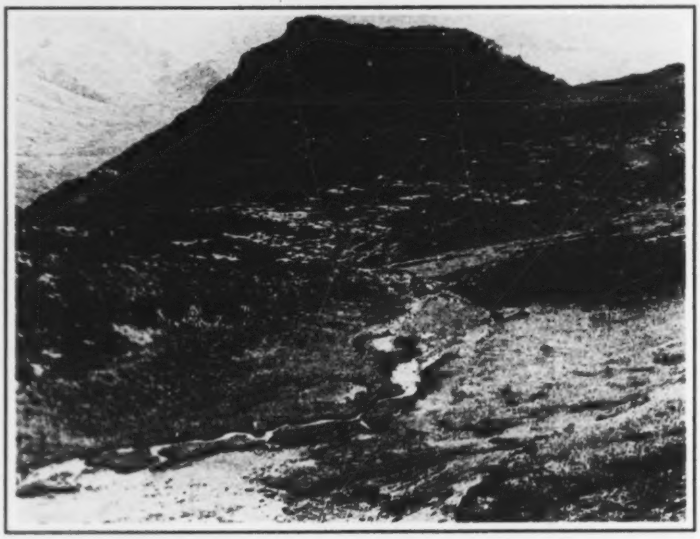


Fig. 7.24: Nivation hollow on Mount Anne.

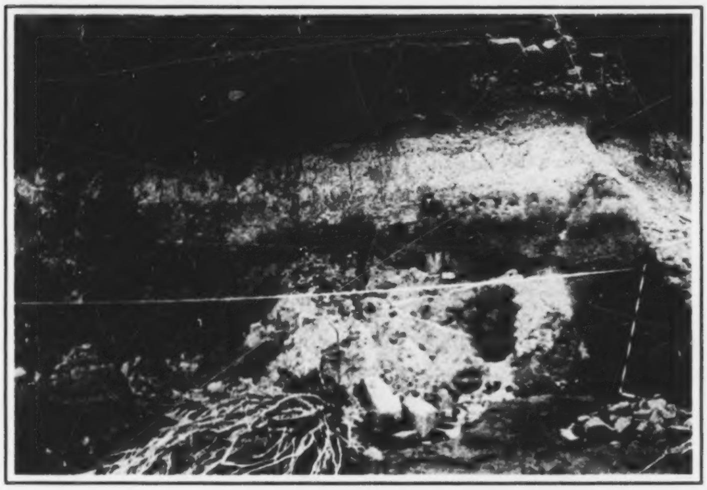


Fig. 7.25: Solifluction deposits developed from Jurassic dolerite at Monpeelyata Canal. The thick palaeosol in the lower part of the section was probably formed during the Last Interglacial.

than one period of cold climate. The thin local fossil soils indicate intervening brief periods of land surface stability, while the deep and extensive fossil soils may represent long warm interglacial periods.

On the dolerite uplands the downslope removal of chemically weathered clays by solifluction processes or by washing may either leave a lag of corestone boulders or expose the bedrock to fracturing by frost processes. These, and other processes, tend to produce extensive accumulations of blocks of 0.5 to 2m and over in size on the summit plateaux and on the gently inclined upper slopes. Such accumulations are known as blockfields. Where slopes are steep or where there is a headwall above the slope such blocks may accumulate as thick talus or scree deposits. Though some screes, composed of small fragments and at high altitudes (over 1100m), are still active the greater proportion of coarse blockfield and scree deposits throughout Tasmania are inactive, being relics from the periods of glaciation (Fig. 7.26).

The blocks that form blockfields and screes may creep gradually downslope aided by the presence of interstitial ice. Where two slopes are opposed or where one steep slope ends on the margin of a shallow valley the blocks will accumulate in the valley and will move down the axis of the valley as a block stream. The best block streams occur in the uplands of Jurassic dolerite, with impressive examples developed on the Ben Lomond Plateau, on Mount Wellington, and below Lake Fenton at Mount Field (Fig. 7.26).

Although many other minor forms have resulted from the action of snow and frost in the mountains in past times when it was considerably colder than present, it is the development of screes, blockfields, blockstreams and thick solifluction deposits that are the most extensive and most important features that characterise the former alpine periglacial environments of Tasmania.

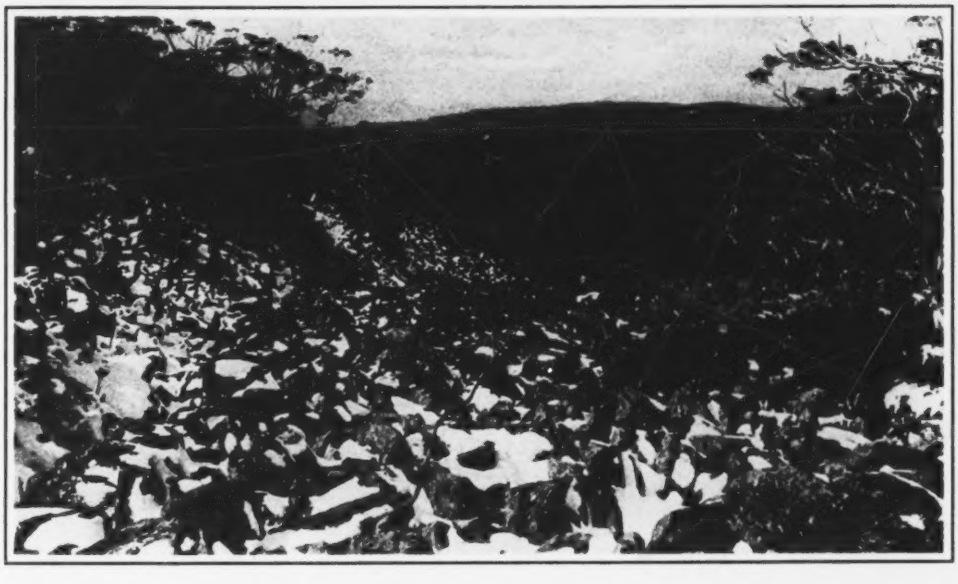


Fig. 7.26: Block stream of Jurassic dolerite below Seagers Lookout at Mount Field National Park.

Chapter eight

The effects of wind

Doug Ewington

Introduction

The Tasmanian landscape contains a number of landforms produced as a result of wind action. The effects of wind are most apparent in areas where vegetation cover is sparse. It contributes to the development of landscape features in arid (desert) regions and such places as the coastline, areas of loosely cemented sandstone, areas of glacial outwash, ploughed fields and stream valleys containing fine sediment on the flood plains.

Whilst wind action is now playing a part in the formation of Tasmanian landforms (particularly around the coastline and on the Bass Strait islands) its effects were much greater during the Pleistocene glaciations.

The work of wind

Of the three main agents of erosion—**water, ice and wind**— wind is the least competent. The energy of moving air can be compared to that of moving water, as shown by Figure 8.1.

While with moving air there is the same relationship between velocity and diameter of particles transported as we find with water, there is a marked difference in the size of particles transported. Larger particles will never be moved by the wind acting alone. Consequently the wind can play a major role in the sorting of material of varied grainsize and those particles carried by the wind will have an erosive role on larger particles and outcrops that they encounter while in motion.

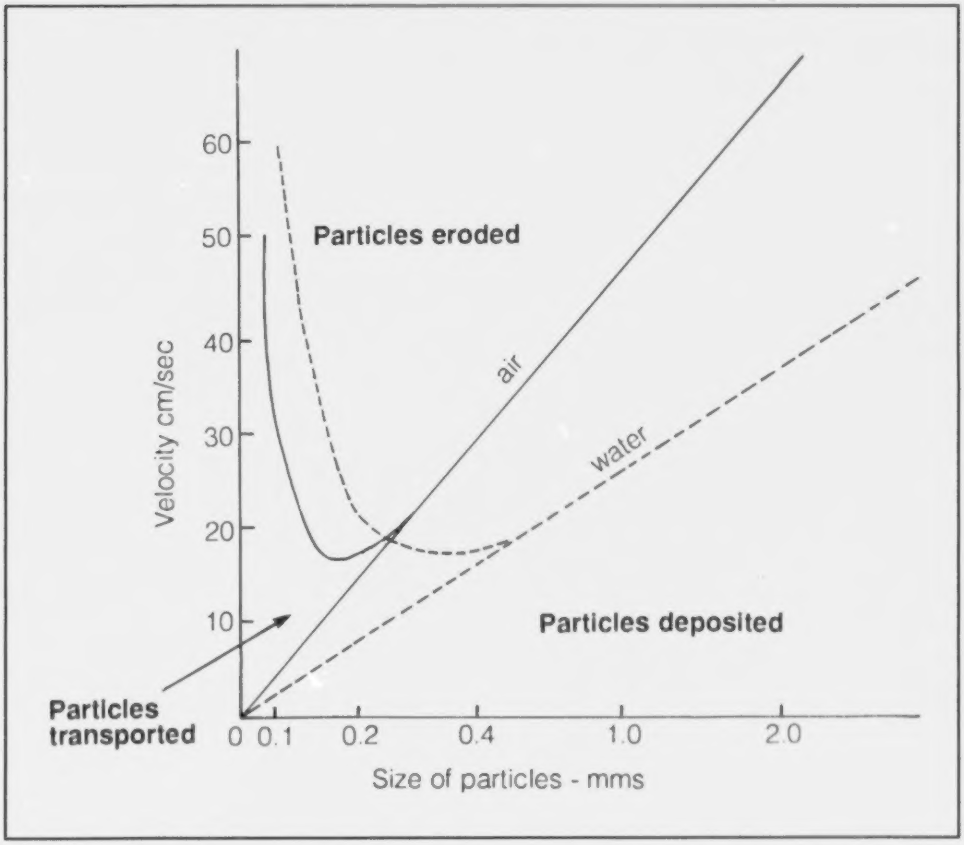


Fig. 8.1: A comparison between velocities at which wind and water erode, transport and deposit particles of different sizes.

The wind's load

To better understand wind erosion and the landforms produced, we must now consider the load carried by the wind. While it varies greatly, depending on the wind's velocity, it can be divided into three major components:

- **suspended load,**
- **saltation load,**
- **rolling and sliding load.**

The **suspended load** of dust-sized particles is made of the material fine enough to be carried in moving air. Its volume and grain size will depend upon the wind's velocity, as well as the availability of such fine material in the environment. This component of the load will be at a maximum in areas such as glacial outwash zones where large quantities of rock flour are present. While such areas do not exist in Tasmania today, the Pleistocene glaciations produced large quantities of rock flour, so we can expect that considerable suspended loads were carried by the wind during these periods.

Saltation is a 'skipping' process. Rounded sand grains are first set in rolling motion by the wind. Some of these grains, upon striking a larger object will become airborne and then follow a parabolic path determined by the wind velocity and mass of the grain.

The total volume of the saltation load is high in areas where wind velocity and the availability of suitably sized sediment are favourable. Anyone who has sat on a dryer part of a beach on a windy day is familiar with this process. The sand particles do not normally rise to any great height, and one can frequently avoid them on the beach simply by standing up.

These sand grains of the saltation load, moving within a few centimetres of the ground, provide the main erosive power of the wind.

The **rolling and sliding load** is composed of those particles too large to be saltated, even at relatively high wind velocities.

Erosion by the wind

Wind of sufficient velocity may physically remove quantities of very fine, dry, incoherent sediments. This is the process of **deflation** and provides the wind with its suspended load. **Blow-outs** are landscape features produced when deflation removes noticeable amounts of sediment from areas such as dunes.

As already mentioned, the saltation load plays an important part in wind erosion. The moving sand particles strike one another, other rock fragments and solid bedrock with an action which can be compared to industrial sand blasting. These collisions involve the processes of **abrasion** and **attrition**. The particle or surface struck by the moving sand suffers abrasion in which the sand grains themselves are worn away and are said to suffer attrition. These collisions vary from those taking place in water where the presence of the liquid tends to 'cushion' the collision. Sand grains which have been involved in abrasion and attrition can be readily recognised as such under the microscope from their pitted and frosted surface — unlike those which have been transported and deposited by water.

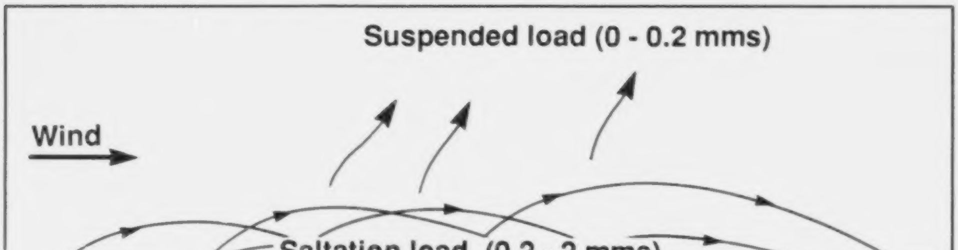


Fig. 8.2: The saltation or bed load moves as a series of bouncing grains. The maximum height to which the grains bounce is two metres, but most grains are concentrated close to the ground. The suspended load is carried high above the ground in the form of dust clouds.

The continued abrasion on the surfaces of a pebble exposed to sand-laden winds tends to cut one or more distinct faces on the pebble, producing a **ventifact**. An undisturbed ventifact in a sediment or rock of any age may be of considerable use in indicating the direction of the prevailing wind at the time the pebble was exposed to abrasion.

Abrasion by saltated sand grains in arid regions frequently undermines rock outcrops close to the ground and strange mushroom-shaped pedestals may be produced. Where the edges of beds of rock which have varying resistance to abrasion are exposed to the wind, an elongated groove or trough may develop where the weaker strata are eroded at a great rate - a **yardang.**

The role of water and vegetation

Before further considering the landforms produced by wind erosion, some consideration should be given to the overall picture in areas where rainfall and vegetation cover work with the wind in the overall development of the landscape. In Tasmania the relatively high rainfall as well as widespread and frequently dense vegetation tend to mask from sight processes of wind erosion.

Apart from sandy coastal areas, the major erosional activity by wind in Tasmania occurs only when areas of fine sediment are left exposed by other agents. This may occur:

- in a river valley following a flood that has deposited fine material on a flood plain;
- when a large grassed area is ploughed;
- when complete clearing of a forest takes place.

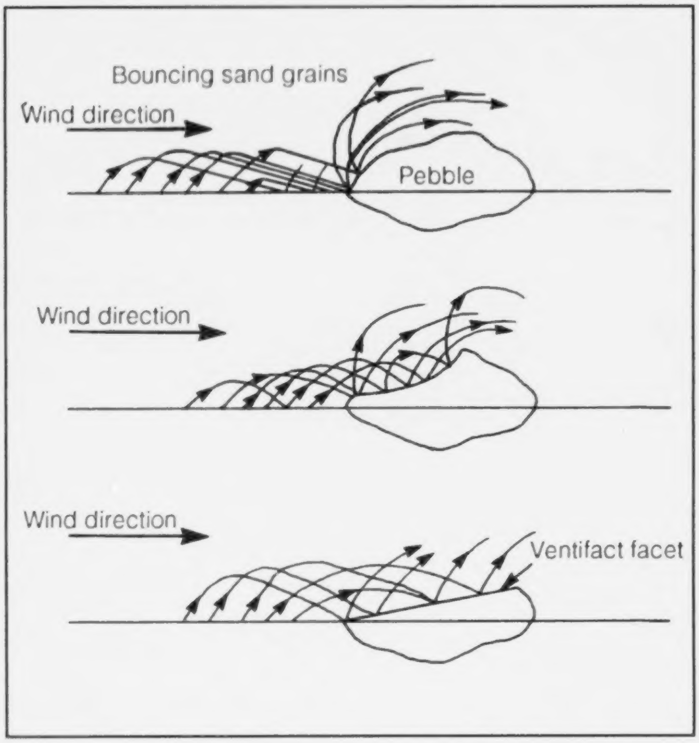
Deposition by the wind

Sand dunes

In non-coastal areas the two main factors controlling dune development are sand supply and the nature of the land surface. Prevailing wind direction, vegetation and rainfall are also involved.

When sand supply is limited, the wind heaps the sand into crescent-shaped dunes. While the height and width are controlled by a variety of factors including average wind velocity, one major feature of these dunes is the direction in which the 'horns' of the dune point. This is controlled by the surface over which the dune is moving.

Fig. 8.3: Stages in the production of a facet of a ventifact.



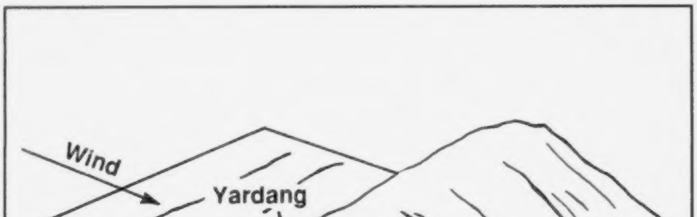


Fig. 8.4: A yardang - an elongated ridge between troughs formed by the erosion of the weak stratum between more resistant strata.

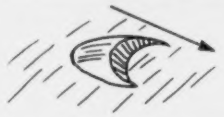
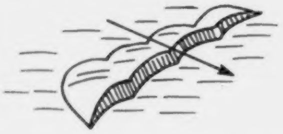
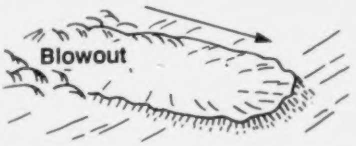
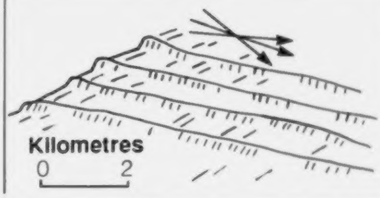
Kind	Definition and Occurrence	Illustration (Arrows indicate wind directions)
Barchan dune	**A crescent-shaped dune with horns pointing downwind.** Occurs on hard, flat floors in deserts; constant wind, limited sand supply. Height 1m to more than 30m.	
Transverse dune	**A dune forming a wavelike ridge transverse to wind direction.** Occurs in areas with abundant sand and little vegetation. In places grades into barchans.	
U-shaped dune	**A dune of U-shape with the open end of the U facing upwind.** Some form by piling of sand along leeward and lateral margins of a growing blowout in older dunes.	
Longitudinal dune	**A long, straight, ridge-shaped dune parallel with wind direction.** As much as 100m high and 100km long. Occurs in deserts with scanty sand supply and strong winds varying within one general direction. Slip faces vary as wind shifts direction.	

Fig. 8.5: Dune types.

On a relatively smooth surface the horns of the dune, containing less sand than the higher dune centre, move ahead of the dune centre thus producing a crescent with its horns pointing downwind, a **barchan.** If however, the surface is gravel, tall grass or some other material which will slow down the forward movement of a small heap of sand, the downwind migration of the horns will be slowed down while the centre of the dune moves ahead unhindered. This produces a crescent dune with its horns pointing upwind, a **parabolic dune.**

When there is a relatively unlimited supply of sand the wind piles the sand into ridges or 'waves'. These do not always move with the wind direction once they have been established.

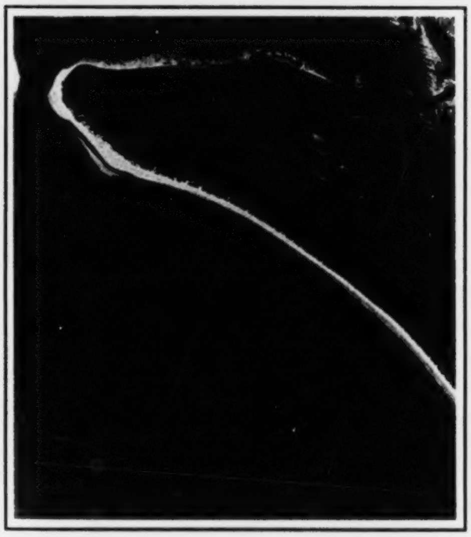
Transverse dunes are ridges of sand formed at right angles to the dominant wind direction. They attain considerable height and like barchans, have a gentle windward slope and a steeper lee face. They move slowly forward with the prevailing wind, and frequently deviate from a straight line across the wind because of irregularities in the surface they are moving across.

Longitudinal dunes are essentially linear and ridge-shaped, reaching a height of up to 200 metres under ideal conditions. Winds blowing along the general line of the dune cause them to grow in length, while other winds blowing across the line of the dunes build them higher. Many areas of central Australia are covered by series of winding seifs, often many kilometres in length. Excellent examples are found in the Simpson Desert.

In some of the major arid regions of the world complex sand seas have developed. In these areas many factors influence dune shape, so that a complex, ever-changing mixture of dunes of finer sand develops on a blanket of coarser sand. A few small patches of this type are found in areas of central Australia.

Vegetation developing in a dune area may stabilise the dunes so that their overall shape changes little from year to year. When such stabilisation has occurred, removal of vegetation will be followed by rapid movement of large quantities of sand, frequently destroying remaining vegetation by burial or undermining. Farmers in coastal areas of

Fig. 8.6: Aerial photograph of coastal dunes in the Smithton area (NW).



Tasmania, particularly between Bridport and Cape Portland, must keep watch on the vegetation on their coastal dunes, since any major blow-out can result in massive sand migration onto inland pastures.

Coastal dunes tend to be more complex in their shapes and movements. Variation in weather has greater effect on coastal dunes than it does on the dunes of inland areas. One major storm may cause drastic changes to dunes which have been stable and unchanged for years. In general, coastal dunes take the form of inland-migrating ridges of sand moving before the wind, but irregularities in the coastline, vegetation and rock outcrops may cause major variations to their shape.

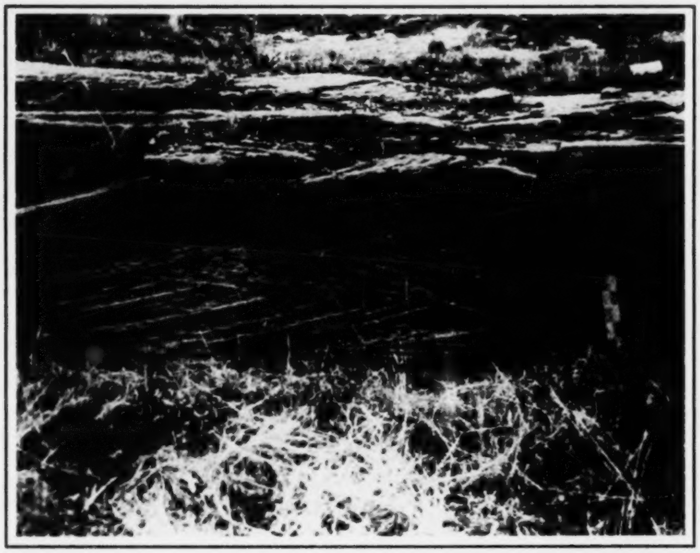
Older wind deposits

The effect of wind in shaping Tasmanian landforms has varied in direct proportion to the level of aridity and lack of vegetation cover. It is thought that wind erosion would have been far more effective during the Precambrian and early Palaeozoic times, prior to the evolution of land-based plants.

Cross-bedding patterns in Triassic sandstones near Melton Mowbray (Fig. 8.7) appear to have been formed by the action of wind. This may be indicative of more arid conditions during this period of Tasmania's geological history.

During the Quaternary (the last 2 million years) the effects of wind would have increased during the colder glacial periods. Lower rainfall, sparse vegetation cover and stronger westerly winds all combined to allow the formation of a range of aeolian landforms.

Fig.8.7: Aeolian cross-bedding in Triassic sandstone near Melton Mowbray.



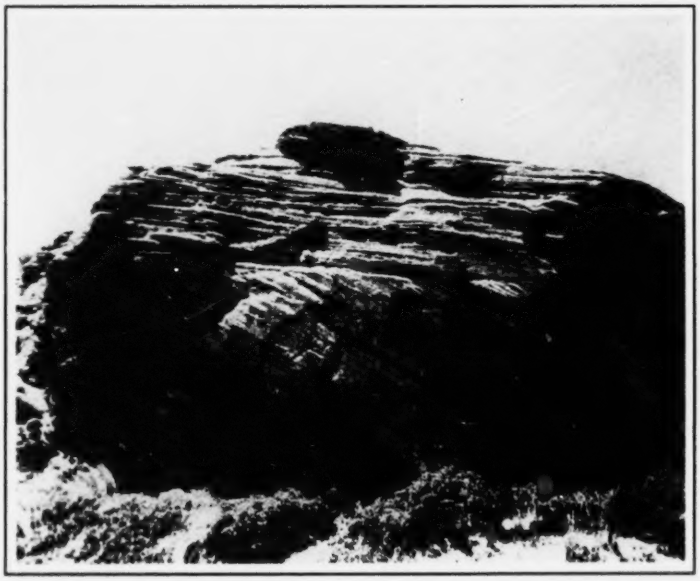


Fig. 8.8: Aeolian cross-bedding in Quaternary sandstone near Marrawah (far NW).

Fixed inland deposits

Extensive **sand sheets** are found almost exclusively along the eastern side of many Tasmanian river valleys such as the South Esk, Lake and Macquarie Rivers of the Launceston Basin, the Derwent River between Ouse and Bridgewater, and the Jordan and Coal rivers. These sheets vary in thickness from a few centimetres to several metres and in area from a few square metres to upwards of fifteen square kilometres. Most overlie all but the youngest alluvium and generally assume the shape of the underlying formation, although some do approach dune form. Clear evidence now exists for at least two periods of aeolian deposition, before, and then during the closing stages of the last glacial epoch.

In some places these sheets have been found up to 100 metres above the valley floor. The primary origin of these sands appears to have been deflation of fine sands from heavily aggraded river beds and floodplains during periods of lower sea level. Meltwater would have swollen the rivers at the close of a glacial and large quantities of fine sediment would have been carried down rivers such as the Derwent and the South Esk. The next glacial would see these sediments left well above the reduced river, to be redistributed by the prevailing cold westerly winds. The general absence of cross-bedded structures in the sands suggests that they mainly accumulated by being trapped on vegetated surfaces.

In the lower Derwent area, particularly around Dromedary and Bridgewater, the sands are associated with alluvial fan sediments which themselves can be related to increased river flows associated with the close of a glacial. The lower of the two levels of sand, often strongly leached, rests upon fan sediments and is in turn overlain by other fan materials. Studies have shown a relationship between the upper level of sands and the post-glacial thermal maximum, about 5,000 years before present day.

Considerable attention has been given to the question of what happened to the finer silts. In general it has been accepted that much of it became incorporated in soil horizons east of the sand sheets. Field studies of soils support this theory.

A **lunette** is a crescent-shaped dune of clay, silt and sand found on the eastern side of lakes, lake beds or swamps. They are very common in Tasmania, particularly in the Midlands and parts of the east coast. Figure 8.9 shows the outlines of a number of larger and smaller lunettes in the Longford area. The dunes developed during relatively dry periods when fine sand, silt and clay were exposed by the lowering of the water level in a lake or swamp, allowing wind transport of the sediment.

A date of 9,550 + 500BP from basal peat sitting on lake floor shelly sand and clays at Lake Tiberias indicates a minimum age of Late Last Glacial Stage for the Lake Tiberias lunettes.

Coastal dunes

Many coastal dunes are sand ridges that, in general, parallel the present coastline (see Fig. 8.6). They are thought to have originated as beach berms built by normal waves. One suggestion is that the ridges were built when sea level was dropping. The berm may have acted as a nucleus for windblown sand, most of which was moved in by onshore winds.

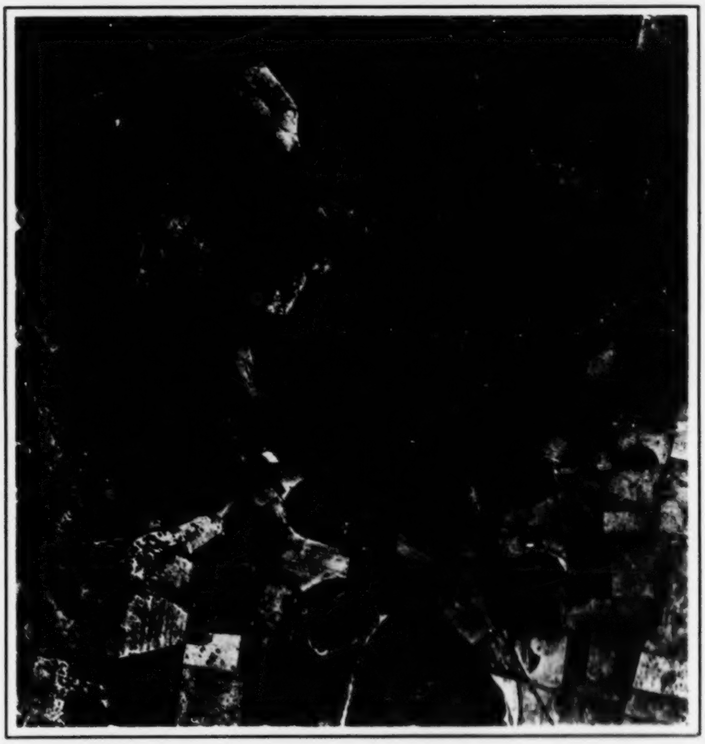


Fig. 8.9: An aerial photograph showing a number of lunettes of varying size in the Longford area.

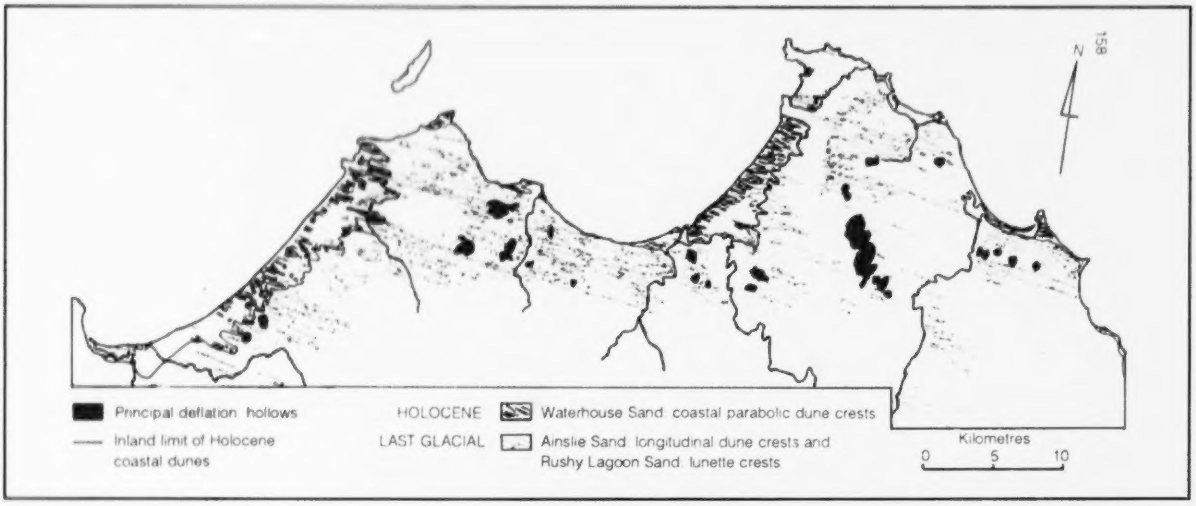

N
158
Principal deflation hollows
Inland limit of Holocene coastal dunes
HOLOCENE
Waterhouse Sand: coastal parabolic dune crests
LAST GLACIAL
Ainslie Sand: longitudinal dune crests and Rushy Lagoon Sand: lunette crests
Kilometres
0
5
10

Fig. 8.10: Holocene and Last Glacial Age linear dune systems of coastal northeastern Tasmania.

A number of studies have recognised at least two stages of dune formation. Figure 8.10 shows a map of coastal northeastern Tasmania from Bowden (1983). It shows two prominent areas of Holocene parabolic dune crests on exposed west-facing stretches of coast. Figure 8.11 is an aerial photograph showing the prominent WNW-ESE orientation of these parabolic dunes. They are often sparsely vegetated and are migrating inland.

Figure 8.10 also shows extensive fields of Last Glacial Age longitudinal dunes (approximately 350km^2). Like the younger parabolic dunes they have a prominent WNW-ESE orientation. Evidence from the dune field suggests that conditions were probably colder and drier during their formation, and the westerly winds were stronger. Bowden has related these changes to climatic conditions between 22 thousand and 10 thousand years ago (Late Last Glacial Stage). There appears to be strong evidence that during this time there was a period of major aridity which caused the drying of lakes, construction of lunettes and development of longitudinal dunes.

At least two phases of dune formation have also been recorded on King and Flinders Islands. Longitudinal dune fields of similar form, occurrence and soil profile development from those in northeastern Tasmania can be recognised on Flinders Island.

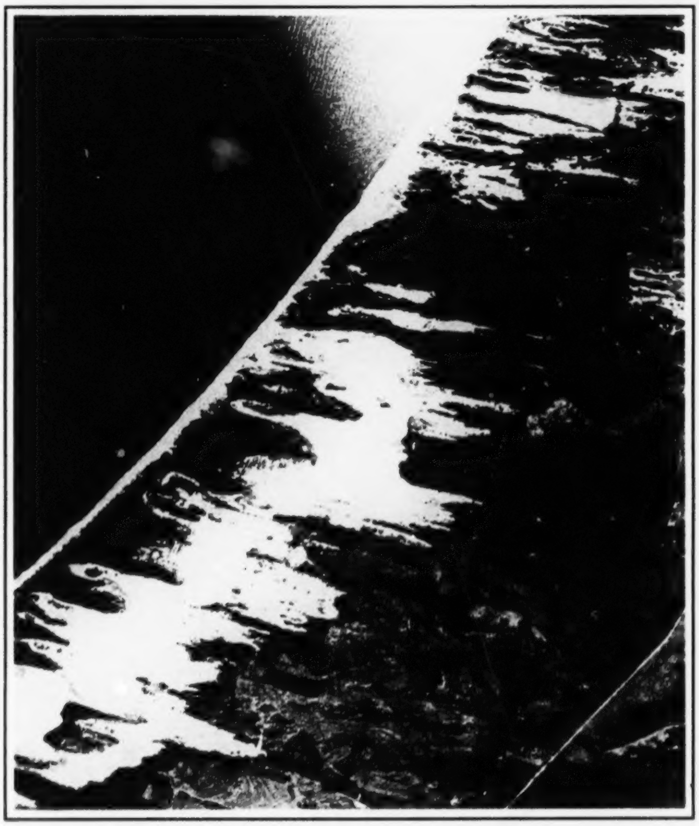


Fig. 8.11: Aerial photograph. Linear Dune Systems, Waterhouse Beach, northeastern Tasmania.

Chapter nine

The geological history of Tasmania

Andrew Scanlon

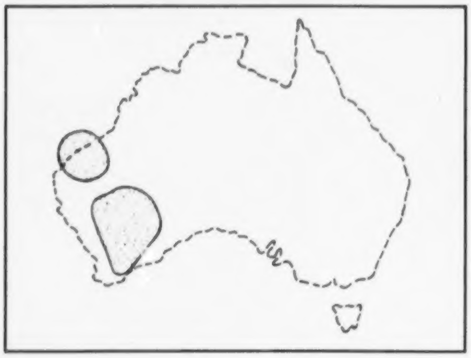
The first rocks (1,000 million to 650 million years ago)

Australia's oldest rocks are found in Western Australia (Fig. 9.1).

Over billions of years the Australian continent has grown eastwards. Volcanoes have erupted along its eastern edge. Thick layers of sediment built up off-shore. These were folded and uplifted to form mountains. Large masses of granite intruded into these new mountain chains. The process repeated itself several times. Queensland's Great Barrier Reef can be considered a new eastward growth.

Tasmania has a zone of very ancient metamorphic rocks running from Port Davey to Forth (Fig. 9.2). They are up to 1,000 million years old. Conditions then were very different from those of today. Much of the Earth's land-surface was like a desert. There were no plants to prevent rapid erosion. Fierce winds picked up grains of quartz and finer particles of clay. The quartz grains were rounded by the constant battering they received as the winds moved them to and fro.

Fig. 9.1: The oldest Precambrian areas of Western Australia.



A shallow sea covered the area that is now Tasmania. Clay and rounded quartz grains were washed in from the nearby desert areas. Layers of mudstone and sandstone slowly formed. Today these rocks are very different (Fig. 9.3). They have been folded several times and changed by metamorphism to schist (a rock rich in mica) and quartzite.

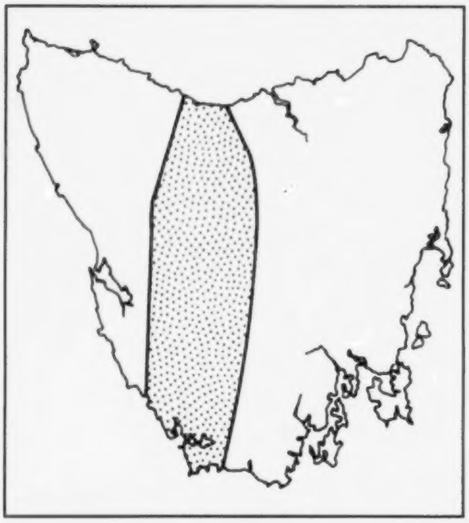


Fig. 9.2: Tasmania's oldest rocks occupy the shaded area.

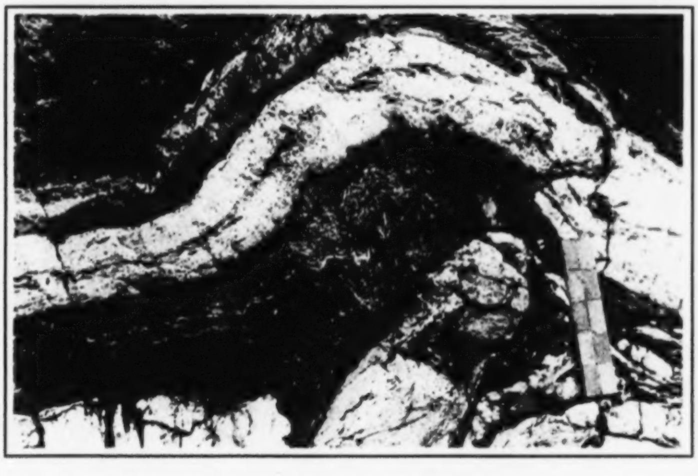


Fig. 9.3: Highly folded metamorphic rocks at Strathgordon.

These old rocks today dominate many areas of south-western and central Tasmania. Quartzite is very tough and resists erosion. It forms mountains that tower over buttongrass plains underlain by weaker schist.

Geologists are uncertain about the exact age of these ancient rocks. They are also uncertain about when the different periods of metamorphism and folding took place.

Other old, but less metamorphosed, rocks are found in the north-west of the State. These rocks are given different names in different areas (Fig. 9.4). They are of similar compositions to the more metamorphosed rocks running from Port Davey to Forth.

Fig. 9.5: Open-pit mining at Savage River.

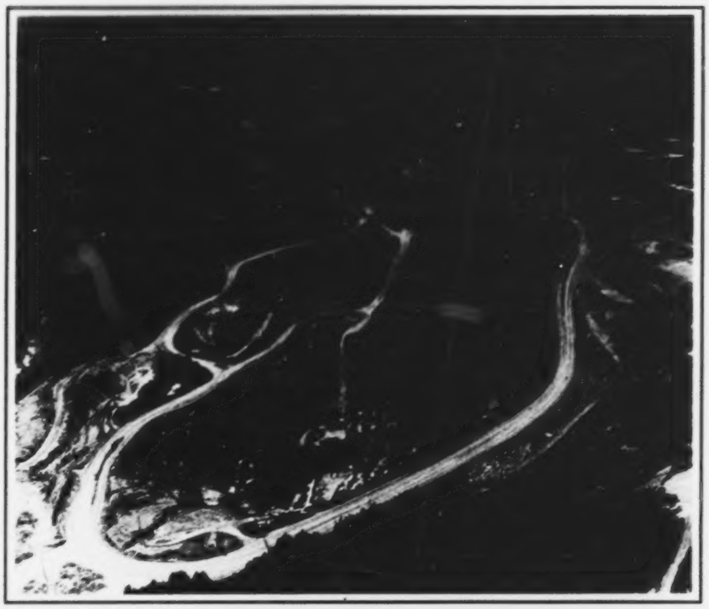
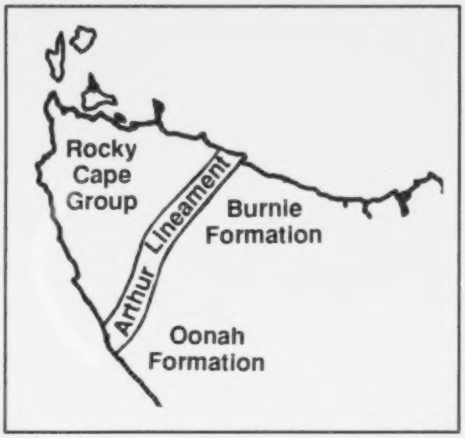


Fig. 9.4: Different names for Precambrian rocks in north-western Tasmania.



Near the end of the period of sedimentation that produced these thick sequences of mudstone and sandstone in north-western Tasmania melts developed deep under the zone known as the Arthur Lineament. Heat from these melts caused groundwater to rise and circulate through cracks and openings in the overlying rocks. As it moved through the rock it dissolved out materials and became rich in iron, sulfur and oxygen. In some places this groundwater poured out on to the shallow sea floor. Large deposits of magnetite (an iron oxide mineral) settled out. These are now being mined in two large open-cuts at Savage River (Fig. 9.5).

Following the formation of magnetite, north-western Tasmania was subjected to a period of squeezing. As a result, folding (Fig. 9.6) and faulting occurred. Dark-coloured dolerite dykes intruded rocks in the Arthur Lineament. Metamorphism affected the whole area, but was particularly strong in the Arthur Lineament.

Rocks west of Maydena and at Badger Head, near Beaconsfield, are similar to those in north-western Tasmania. Quartzite is mined at Beaconsfield and used at Bell Bay (Temco) in the production of alloys of iron and silicon.

Fig. 9.6: Folded Late Precambrian rocks near Burnie.

Fire and water (650 million to 510 million years ago)

Near the end of the Precambrian era (about 650 million years ago), Tasmania entered a period of stretching. Earthquakes and faulting produced a number of narrow depressions separated by high areas (Fig. 9.7). The depressions were covered by seawater and the high areas stood out as island chains.

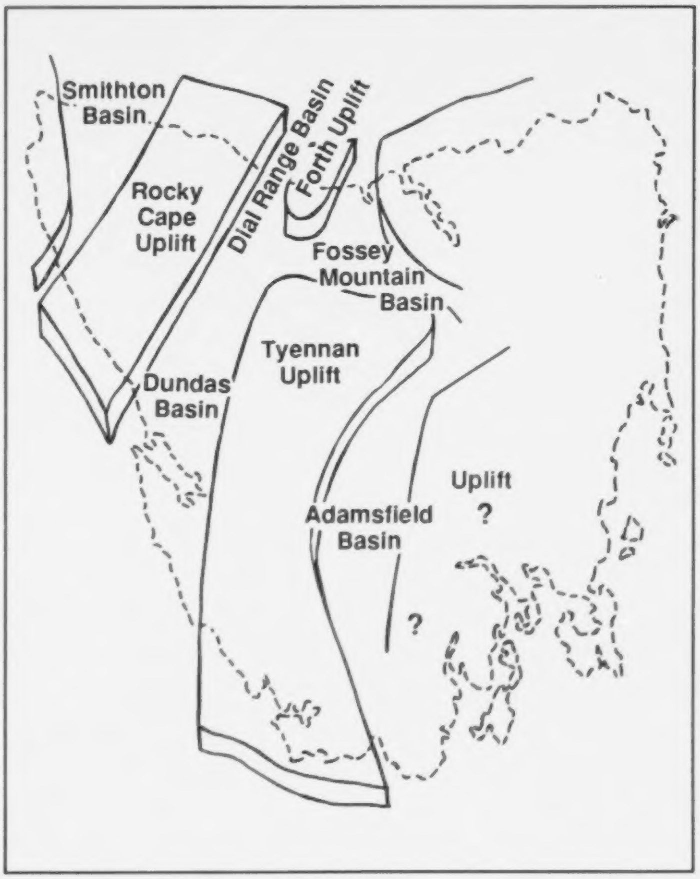
In the shallow areas of the depressions a carbonate mineral called dolomite settled out of the seawater. These sediments now contain Tasmania's oldest fossils - mounds of seaweed and sediment called stromatolites. These organisms have changed little in millions of years. Living examples can be found in a shallow salty bay on the coast of Western Australia (Fig. 9.8).

Stretching caused cracks to develop in the thin crust beneath the depressions and dark-coloured lava flowed out on to the sea floor. The rapid cooling of lava under water produced rounded pillow-shaped structures in the solid rock (Fig. 9.9).

Sand was the first sediment deposited in the depression in western Tasmania (Fig. 9.7). The sandstones that formed as a result are called the Success Creek Group.

The faults around all the depressions were subject to repeated earthquake activity. Sediment slumped and flowed down into the deeper parts of the sea to form layers of the sedimentary rock called turbidite. In western Tasmania thick sequences of mud, with some turbidites and volcanics, slowly accumulated. Geologists call these deposits the Crimson Creek Formation. (Names such as Crimson Creek and Success Creek generally refer to the areas where the rocks were first studied by geologists.)

Fig. 9.7: High areas (uplift) and depressions (basins) in Tasmania about 600 million years ago.



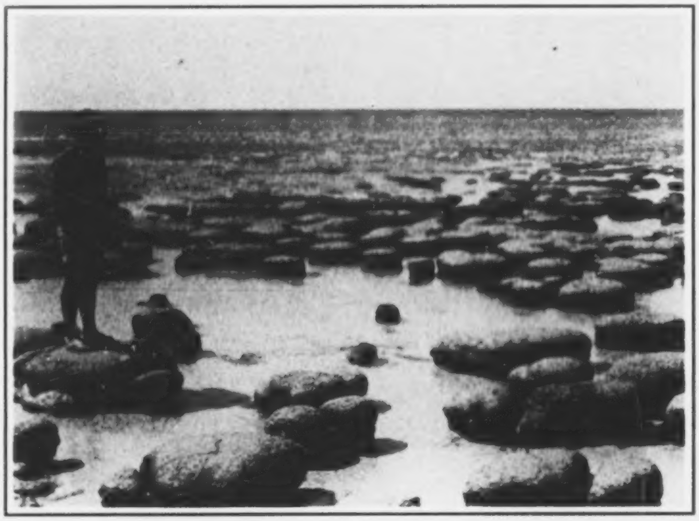
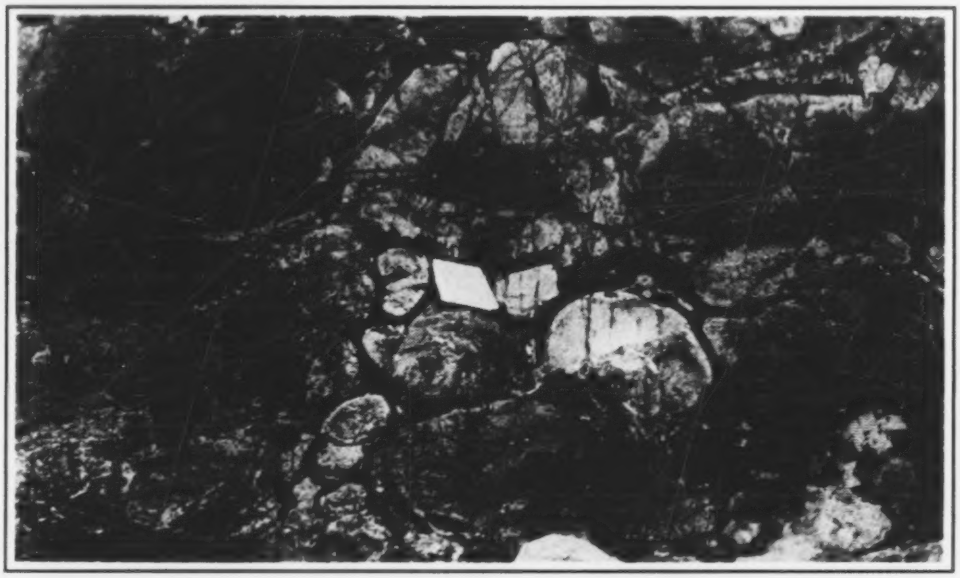


Fig. 9.8: Mounds of algae and sediment (stromatolites) in Shark Bay, Western Australia.

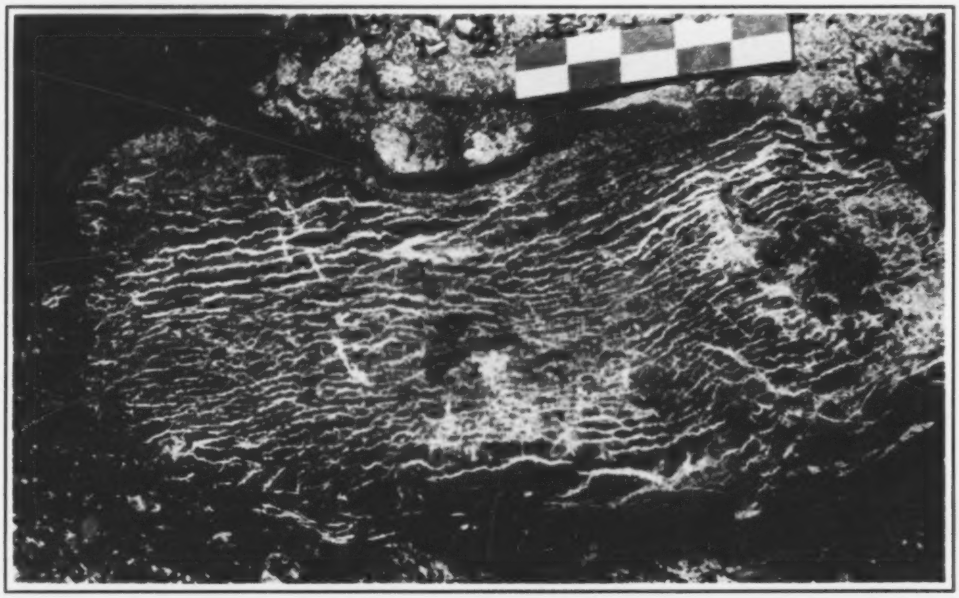
Fig. 9.9: Basalt pillow lavas just south of city of Melbourne Bay, King Island .



About 600 million years ago the period of stretching was replaced by a period of squeezing. Big chunks of the dark igneous rock serpentine (Fig. 9.10) were faulted up from the lower crust into overlying sediments.

The heavy minerals chromite and osmiridium were later removed from the serpentine by erosion and deposited in nearby streams. Osmiridium (more properly called iridosmine) is a mixture of two rare platinum-like metals, iridium and osmium. Early this century miners washed it from river deposits at Savage River and Adamsfield. Chromite is the main ore of chromium and has been mined near Beaconsfield. Nickel minerals are also associated with serpentine in western Tasmania and at Beaconsfield.

Fig. 9.10: Serpentine containing tiny veins of asbestos, near Renison Bell.



Another far more important event started as Tasmania began to be squeezed — a chain of volcanoes began to erupt next to the area of old Precambrian rocks (Fig. 9.11). These volcanoes formed a line of islands on the eastern side of the main depression (Dundas Basin) in western Tasmania. At this time the sea occupied the depression, and the area may have looked similar to some of the volcanic islands south-west of Australia today (Fig. 9.12).

Initial compression (squeezing) exposed parts of the Crimson Creek Formation to erosion. Sediments continued to accumulate in the depression and a thick sequence of mudstone, coarser-grained sediments and volcanics was deposited on top of the Crimson Creek Formation. Geologists call these rocks the Dundas Group. They contain Tasmania's oldest animal fossils.

About 750 million years ago evolution produced the skeleton and a great variety of creatures crawled, swam or floated in the Cambrian oceans. The most abundant and well known of these animals was the trilobite (Fig. 9.13) — a now extinct relation of the crayfish and crab. Tasmania's oldest trilobites are found in Dundas Group sediments. They were small, blind creatures called agnostids.

Fig. 9.11: The line of volcanoes, known as the Mount Read Volcanic Belt, that began erupting during the Cambrian Period.

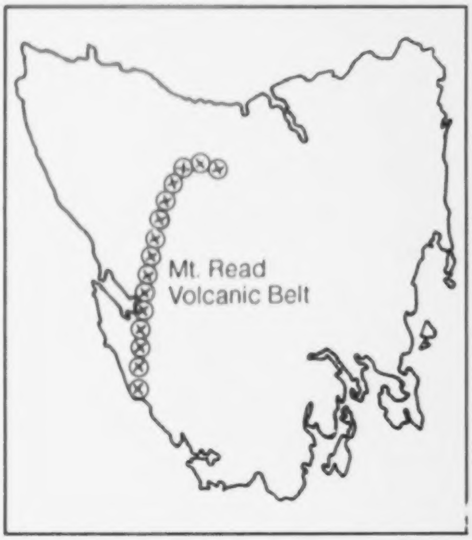


Fig. 9.12: Volcanic islands south-west of Australia (the McDonald Islands, near Heard Island).

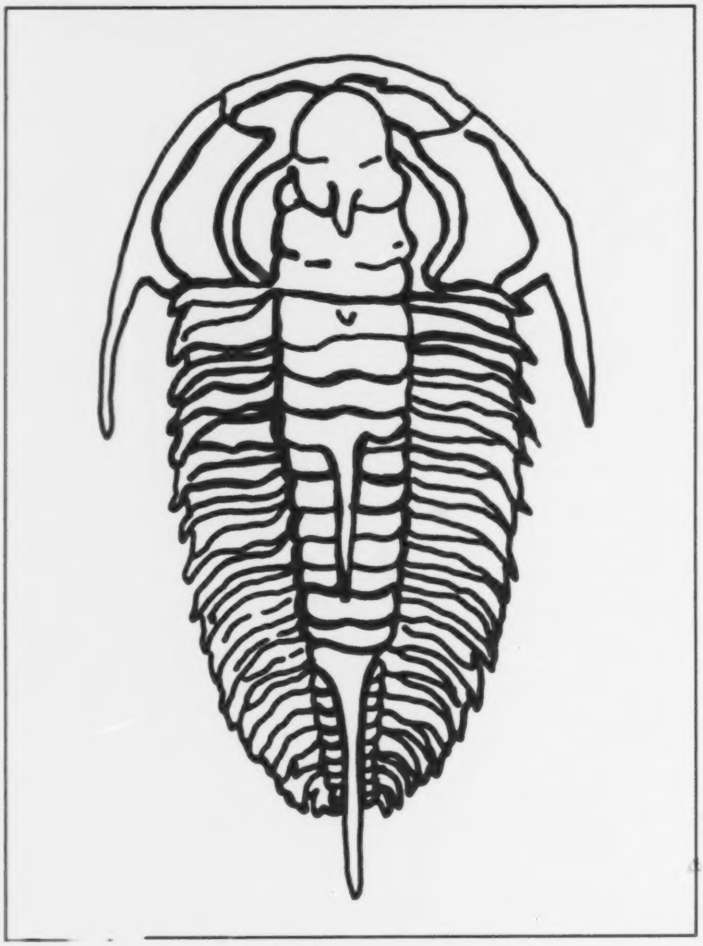


Fig. 9.13: A trilobite, an extinct relation of the crayfish and crab.

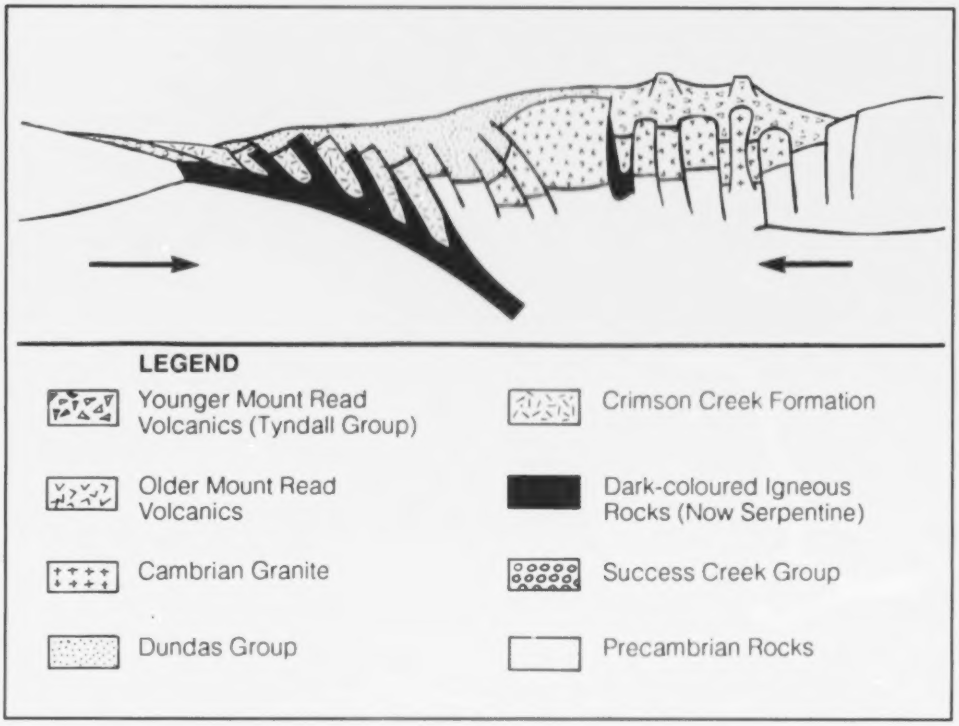

LEGEND
Younger Mount Read Volcanics (Tyndall Group)
Older Mount Read Volcanics
Cambrian Granite
Dundas Group
Crimson Creek Formation
Dark-coloured Igneous Rocks (Now Serpentine)
Success Creek Group
Precambrian Rocks

Fig. 9.14: Possible plate tectonic model for western Tasmania during the Cambrian.

While trilobites swam in seas to the west, volcanoes continued to erupt along the line known as the Mount Read Volcanic belt. The explosions were violent and steep-sided mountains of lava and ash developed. The lava solidified to form rhyolite, a light-coloured igneous rock. Central parts of some volcanoes collapsed to form giant depressions called calderas. Geysers and bubbling thermal pools were common.

Some geologists believe this period of squeezing (or compression) was associated with the collision between two crustal plates. Figure 9.14 shows the proposed easterly-dipping slice of oceanic crust (dark-coloured) beneath the rocks of the Dundas basin and Mount Read Volcanic belt. As the two plates collided the rocks were subjected to faulting.

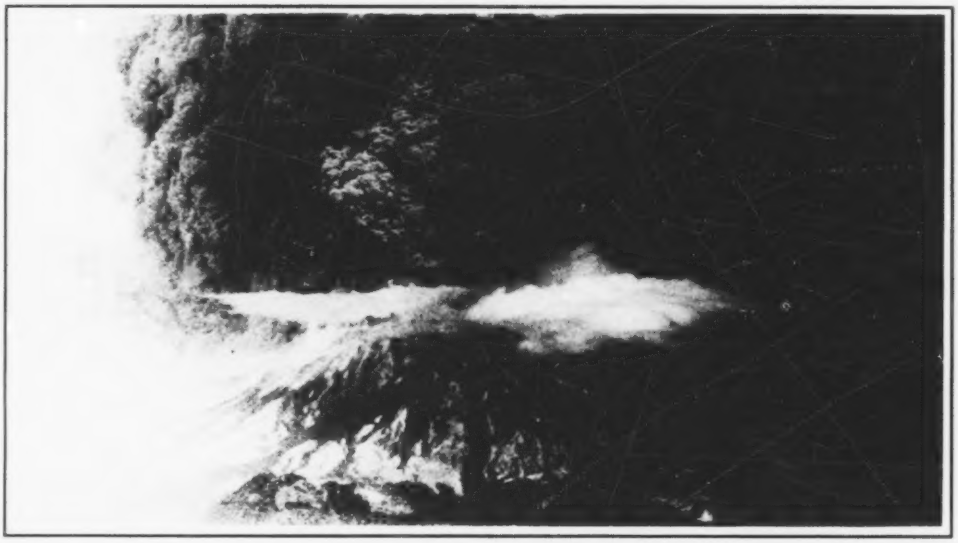


Fig. 9.15: Mount St. Helens, north-western USA, erupting in 1980.

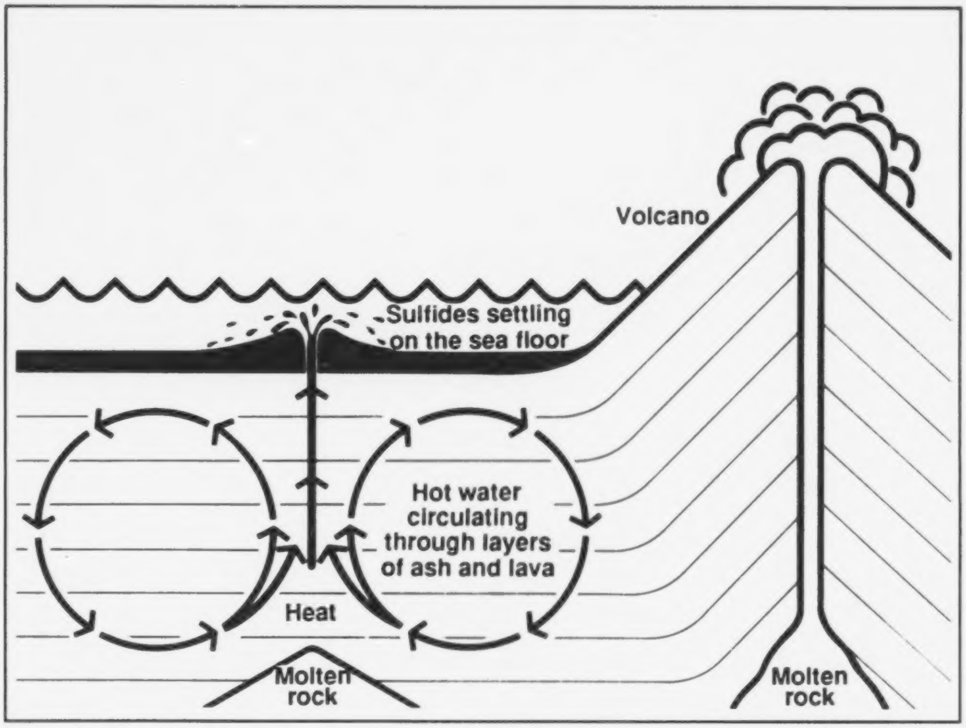

Volcano
Sulfides settling on the sea floor
Hot water circulating through layers of ash and lava
Heat
Molten rock
Molten rock

Fig. 9.16: The formation of metal sulfides on the Cambrian sea floor.

Volcanic activity occurred on and off along the line of the Mount Read volcanic belt for millions of years. During several of the long, quiet periods other events were taking place. Molten magma deep beneath the surface was heating water in the cracks and spaces of the overlying pile of ash and lava. This hot water worked its way upwards and was replaced by colder water from above. This in turn was heated and a circulation system began (Fig. 9.16). As it moved through spaces in the rock the water selectively dissolved small quantities of copper, lead, zinc, silver and gold. Occasionally hot jets of water poured out onto the sea floor and metals, combined with sulfur, settled out as solids. A similar process is occurring today in several places around the globe (Fig. 9.17).

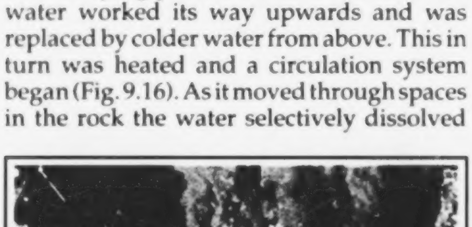


Fig. 9.17: Metal sulfides forming on the floor of the Pacific Ocean.

All rocks contain small amounts of many of the important metallic elements. For these metals to become valuable ores they need to be concentrated in some way. Hot water trickling through rocks can slowly build up large concentrations of dissolved metals and sulfur. Where these trickling solutions encounter different conditions (for example, a heavily fractured fault zone, a layer of soluble rock or cold seawater) the metal sulfides can quickly settle out to form a future ore-body. The Rosebery, Hellyer, Que River and some of the Mount Lyell ore-bodies formed on the sea floor during the Cambrian Period. Other Mount Lyell ores dissolved out and replaced soluble rock layers just below the sea floor.

Volcanic eruptions continued on and off and the ore-bodies were covered by more ash and lava. Occasional earthquakes produced underwater mud-slides. About 510 million years ago earthquake activity increased and the older Precambrian and newer Cambrian rocks were uplifted to form mountain areas.

Quiet times (510 million to 380 million years ago)

The high areas formed late in the Cambrian Period were attacked by the forces of erosion. Water and gravity carried boulders, pebbles, sand and mud down the steep slopes and out on to the plains below. Large alluvial fans, similar to those found in many of the world's deserts, formed at the foot of the slopes. Coarser and more angular particles were left near the high areas. Rounded pebbles and sand travelled further out over the plains.

As the mountains were cut back the sea lapped on to the plains and lower slopes. Rivers flowing into it carried more mud than sand. The thick sequence of mudstone that resulted contains abundant fossils. Figure 9.18 gives an idea of the types of creatures living on the sea floor. Trilobites scurried about in the mud and brachiopods (a type of shellfish) pumped in water to extract food.

In the middle of the Ordovician Period (about 470 million years ago) Tasmania consisted of low land in the north-west, a few islands, large tidal mud-flats and some areas of deeper water. The climate was very warm and due to continental drift we were situated near the equator (in the northern hemisphere).

Between the mudflat/lagoon areas and deeper water were small reefs and patches of coral. Very little sand and mud were being washed into the sea and calcium carbonate was the main sediment. Various organisms were taking carbonate out of seawater. The Sun evaporated surface waters and more carbonate settled out, adding to the build-up. Tasmania slowly sank (subsided) as the sediment accumulated. The carbonate muds and shells were turned into a thick sequence of the sedimentary rock limestone. This limestone is quarried for various purposes at places like Lune River and Railton.

About 430 million years ago, a distant area of land was uplifted and rivers once again carried sands and muds into the shallow sea. Sedimentation continued till about 380 million years ago.

Geologists have given the name Wurawina Supergroup to all the sedimentary rocks deposited from about 510 million to 380 million years ago in western Tasmania. The names Denison Group and Gordon Group are applied to the older conglomerate/sandstone/mudstone and limestone sequences respectively. The terms Eldon Group or Tiger Range Group are variously applied to the younger sandstone/mudstone sequences.

While these shallow marine sediments were forming in western and central Tasmania a quite different environment affected what is now north-eastern Tasmania. Dark-coloured deep-sea muds and then muds and sands slowly accumulated over millions of years. Geologists call these rocks the Mathinna Beds. Just east of the Tamar Estuary the Mathinna Beds are Ordovician in age. Further east they are younger, containing occasional Silurian and Devonian fossils.

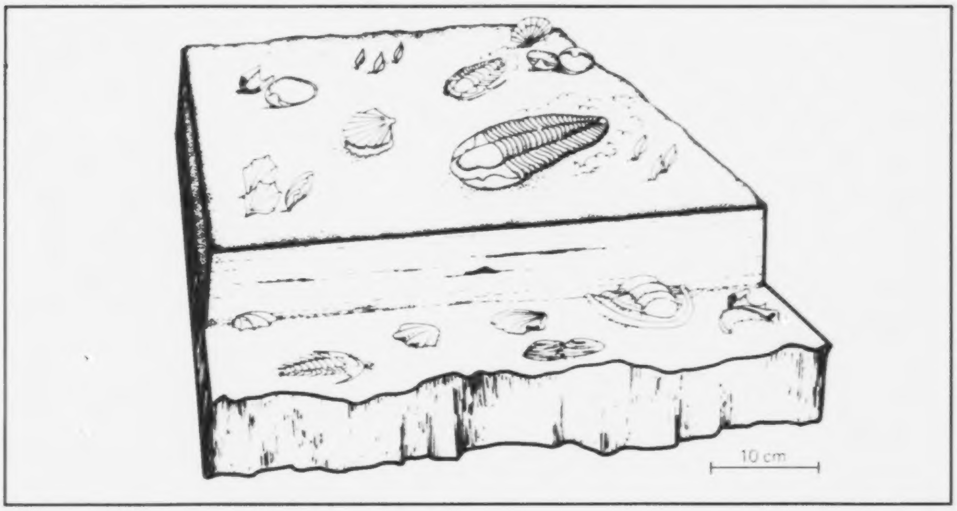


Fig. 9.18: The types of creatures living on a muddy Ordovician sea floor.

Folds, melts and tin (380 million to 310 million years ago)

About 380 million years ago (in the Devonian Period) a major period of mountain building began across eastern Australia. The tough Precambrian metamorphic rocks in central, northern and north-western Tasmania acted as solid blocks and squeezed the younger rocks between them during the uplift. The buckling produced folds parallel to the outlines of the Precambrian rocks (Fig. 9.19). In some areas the folding was accompanied by a small amount of metamorphism to produce rocks such as slate.

As the rocks were folded and uplifted, melting started to take place deep below the high areas. Huge masses of molten granite moved upwards to collect in large, uneven magma chambers beneath much of Tasmania. The melts slowly cooled and large crystals of feldspar and quartz began to form. Heat from the intrusions baked the surrounding rocks (Fig. 9.21). At St. Marys the magma reached the surface to form volcanic rocks such as rhyolite.

The molten granite contained small percentages of a variety of elements. As crystals of feldspar and quartz began to form, some of these elements were left in solution and their concentrations increased. Sulfur, iron, tin, tungsten, gold, silver, lead and zinc remained dissolved in liquids as the granite began to solidify. These metal-rich liquids collected near the top of the granite mass. Some crystallised out in cracks or veins in the granite. Other liquids worked their way up through cracks and openings in the surrounding rocks. They solidified in heavily fractured zones or dissolved out carbonate layers, such as limestone, and solidified there.

These liquids were very important. They produced the silver-lead-zinc ores mined in the late 1800s and early 1900s at Zeehan. They formed quartz veins rich in gold that were the focus of mining booms at Beaconsfield and Corinna. Tungsten-rich liquids formed ores at Rossarden, in the north-east and King Island. The mine at Grassy was, until recently, one of the world's largest tungsten producers.

Fig. 9.20: Folding in Mathinna Beds, north-eastern Tasmania.

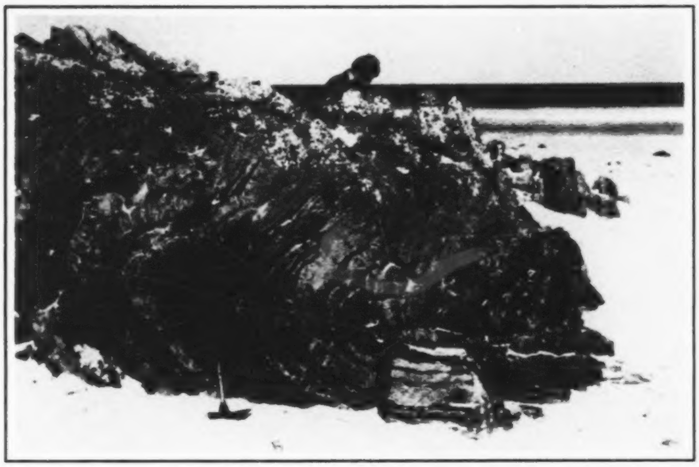
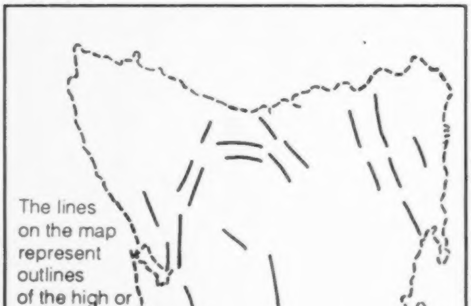


Fig. 9.19: Outline of folds produced during the period of Devonian mountain building.



The lines on the map represent outlines of the high or low areas in major fold structures

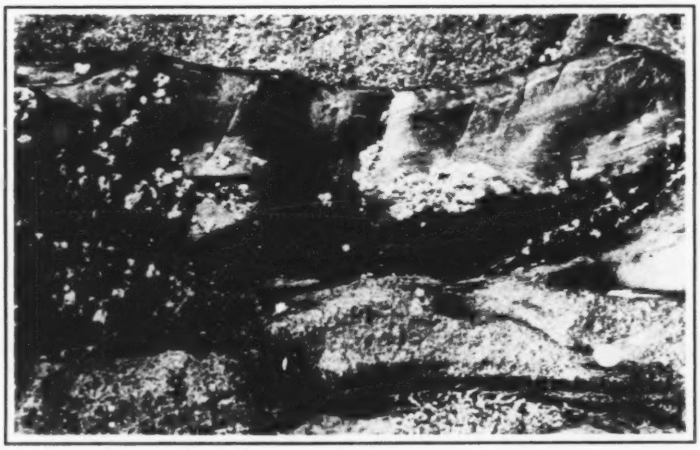


Fig. 9.21: The dark band in the centre of the photograph is sediment that has been baked by the surrounding granite (Bridport).

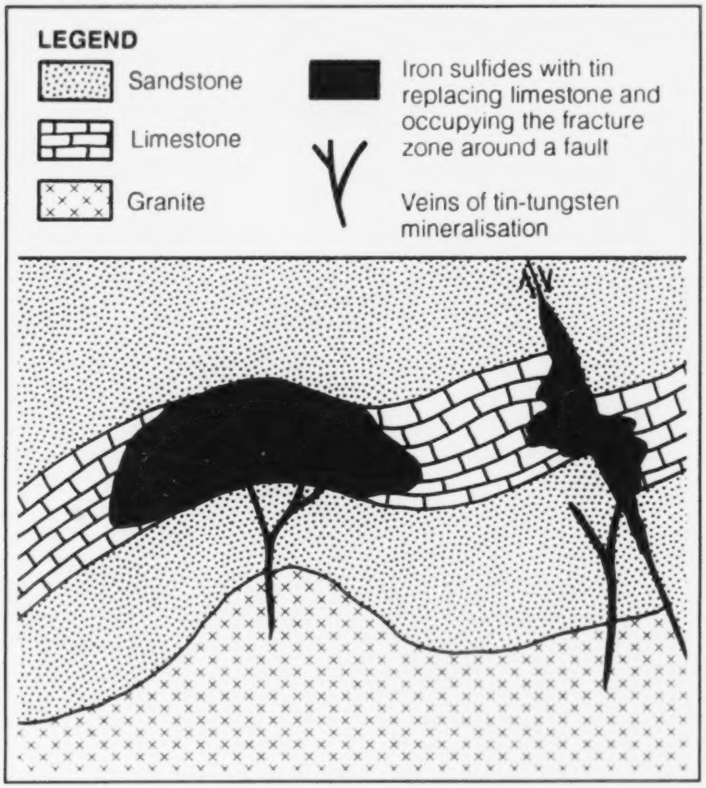


Fig. 9.22: The relationship between granite and associated tin mineralisation.

LEGEND
Sandstone
Limestone
Granite
Iron sulfides with tin replacing limestone and occupying the fracture zone around a fault
Veins of tin-tungsten mineralisation

The most important metal carried by the liquids was tin. Deposits, usually rich in iron and sulfur, often formed at some distance from the granite. At Renison Bell, the world's largest underground tin mine, ores were deposited in a fractured fault zone and as a replacement of dolomite (a carbonate rock). Ores at the recently closed Cleveland mine were replacements of limestone. The relationship between the granite intrusions and tin mineralisation is shown in Figure 9.22.

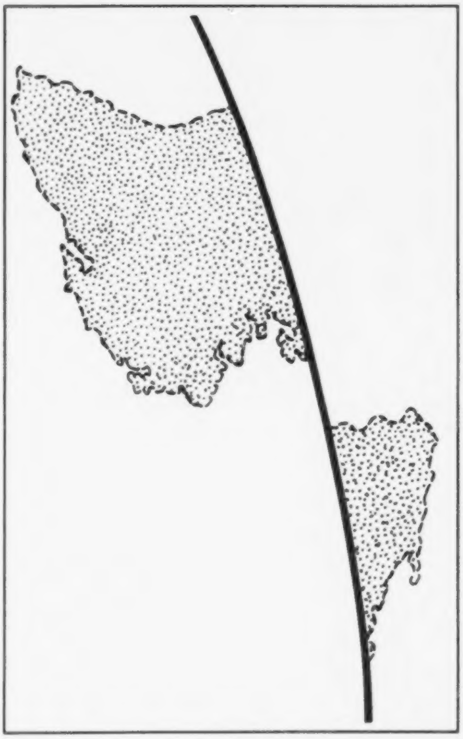
In north-eastern Tasmania erosion of granite and surrounding rock has produced sediment rich in tin. At a number of mines jets of water were used to wash these sediments. Heavy tin ore (cassiterite, SnO_2) settled out and was collected.

Tasmanian granites, now uncovered by erosion in many places, have been radiometrically dated. Ages range from 335 to 365 million years in western Tasmania and from 360 to 373 million years in north-eastern Tasmania. This is a significant age variation between the north-east and west of the State.

As mentioned in the previous chapter the Ordovician to Devonian rocks in western Tasmania are quite different from those in the north-east (the Mathinna Beds). This, as well as the age difference in the granites and certain arrangements of minerals and patterns in folds, has led to an interesting theory. It is thought that north-eastern Tasmania was separated from the rest of the State before 335 million years ago. Between 335 and 300 million years ago the two areas moved next to each other along a major fracture zone called the Tamar Fracture System (Fig. 9.23).

While these events were taking place, erosion had been slowly cutting back the high areas. About 300 million years ago low areas covered much of eastern Tasmania. A few granite mountains were present in the north-east and at Coles Bay. In western Tasmania mountains were composed of tough Precambrian quartzite.

Fig. 9.23: Tasmania and the Tamar Fracture System before 300 million years ago.



Icebergs and swamps (300 million to 200 million years ago)

Tasmanian geology from 300 million years to the present is fairly simple. Between 300 and 200 million years ago a thick sequence of horizontal (flat) sedimentary layers accumulated on the eroded and uneven surface of granite, Precambrian quartzite, and folded sedimentary rocks. Geologists call this horizontal sequence the Parmeener Super-Group. The underlying erosion surface (or unconformity) is well exposed at a few localities (Fig. 9.24).

Tasmania: part of a giant super-continent

Three hundred million years ago all the southern continents and India were joined together to form a giant super-continent called Gondwana (Fig. 9.25).

Tasmania was part of this super-continent and was located close to the South Pole. We were near the edge of a vast ice-sheet that covered a large area of Gondwana. You might recall that about 480 million years ago Tasmania was located next to the equator!

Ice blanketed much of south-western, central and eastern Tasmania (Fig. 9.26). A river of ice (glacier) flowed north from high areas in north-western Tasmania. Meltwaters formed lakes and rivers which flowed into a deep fjord in what is now the Wynyard area (Fig. 9.27).

Fig. 9.26: Tasmania in the late Carboniferous.

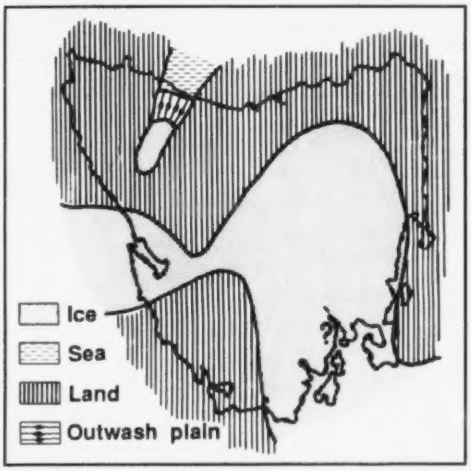


Fig. 9.24: An unconformity separating folded Mathinna Beds from overlying horizontal Permian sediments (Maria Island).

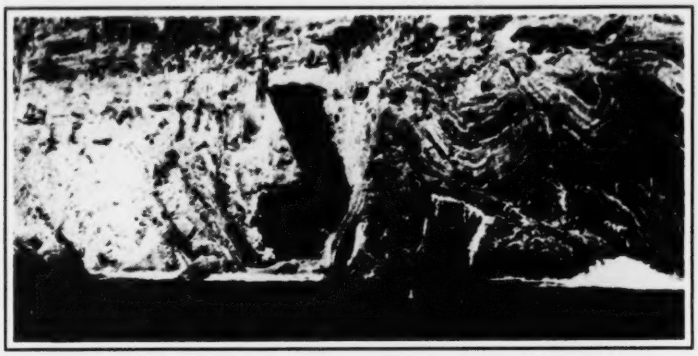


Fig. 9.25: Gondwana.

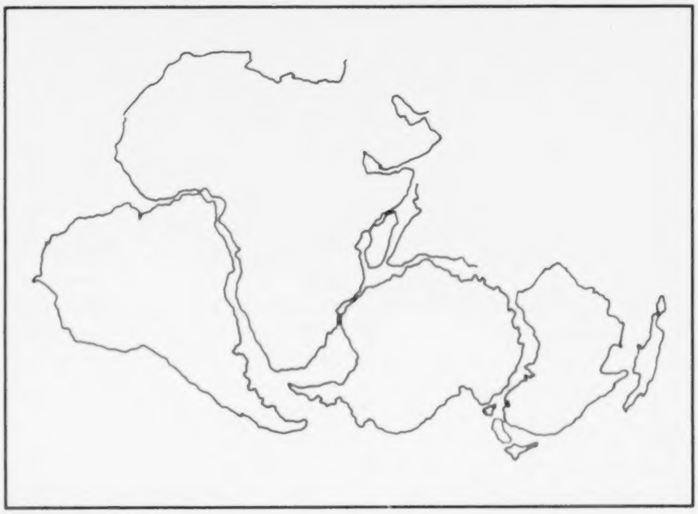


Fig. 9.27: A meltwater lake downstream from a glacier.

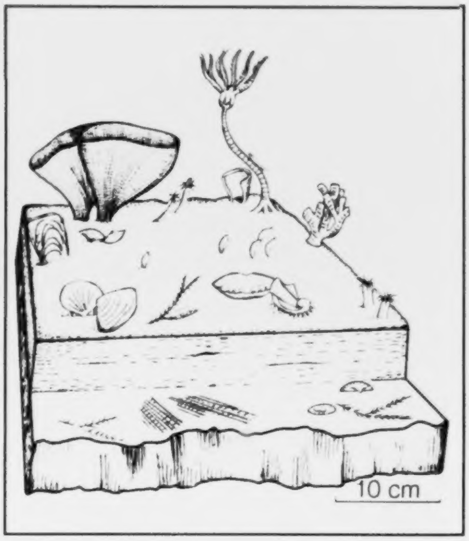


Fig. 9.28: Life on the Permian sea floor.

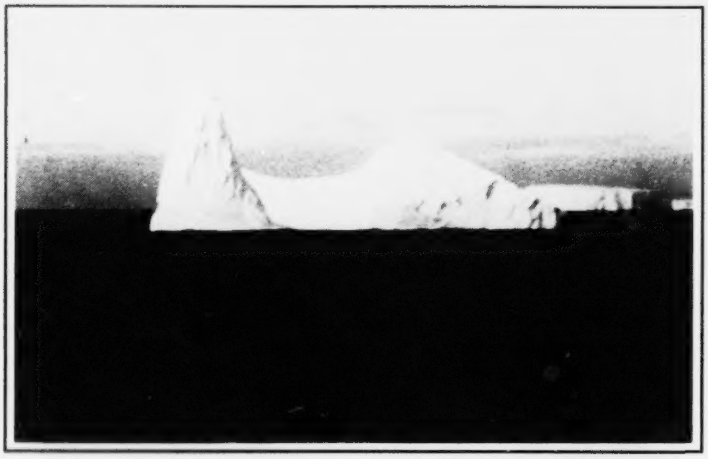


Fig. 9.29: An iceberg.

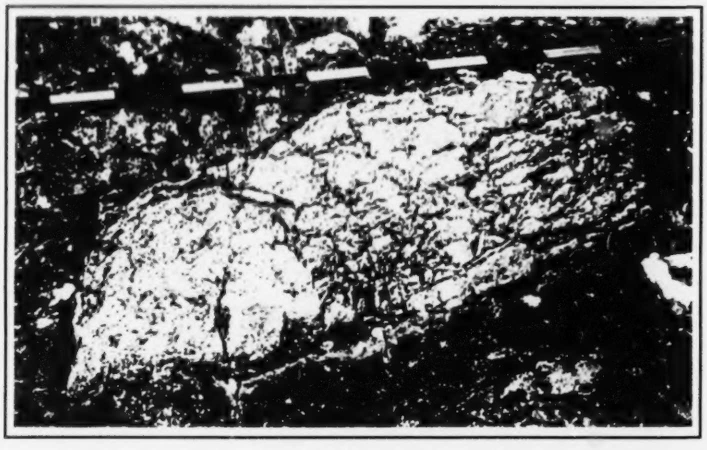


Fig. 9.30: A boulder of granite that sank from a melting iceberg into the mud on the Permian sea floor (Tasman Peninsula).

The sediments at the base of the Parmeener Super-Group consist of: angular boulders, pebbles, sand and clay dumped by ice; river gravels and sand; and thin layers of clay that settled out in lakes. In the Hellyer Gorge, south of Burnie, fossil ferns and the imprint of a dragonfly give an idea of the type of creatures living around the edges of the lakes.

Changes in sea-level

About 290 million years ago part of the ice-sheet melted and sea-level rose to flood large areas of the State. For the next 60 million years sediments accumulated in a slowly sinking depression that widened and deepened towards the south-east. The central parts of this depression follow the line of the Tamar Fracture System.

The first sediments to be deposited on the sea floor were mudstones and some limestone. In the shallow waters of the north of the State algal blooms were common. The water was choked with seaweed and dead plant matter sank to the bottom and mixed with the mud. Today this plant material has been changed to a waxy oil-like substance. It is still mixed with the mud - trapped in the tiny spaces between clay particles in the rock known as oil shale.

Large numbers of shellfish and other organisms lived on the sea floor (Fig. 9.28). Their appearance and lack of variety suggest that the water was very cold. Tasmania was still close to the South Pole and large icebergs (Fig. 9.29) floated in the sea above. As these icebergs melted, pebbles inside sank to the bottom and settled in the mud (Fig. 9.30).

About 270 million years ago an environmental change occurred. It is uncertain whether this was brought about by in-filling of the depression, a drop in sea-level or an uplift of the sea floor. In the north of the State rivers and swamps were associated with the deposition of sand and the accumulation of plant material. Today these are represented by sandstone and thin coal seams. Near Hobart estuaries and deltas widened outwards to the sea.

About 250 million years ago quiet lagoonal conditions covered much of the State. These were replaced by swamps and later still by rivers carrying sand and mud. By the beginning of the Triassic Period (about 240 million years ago), Tasmania was once again a land environment.

Flood plains and swamps

During the early part of the Triassic Period much of Tasmania consisted of poorly vegetated flood plains. Braided streams (Fig. 9.31) and large river channels flowed towards the south-east from higher areas in the far north-west. Mud accumulated in shallow lakes across the flood plains. A seasonal climate allowed the lake beds to dry out and mud cracks to appear. During the rainy season flash floods rolled the dried mud into balls of clay and picked up the bones of dead animals. The flood waters deposited these bones and clay balls, along with sand and mud, in the hollows of channels further downstream. Geologists have removed the bones from some of these clay-pellet conglomerates at places like Old Beach. They have been used to reconstruct the fish, reptiles and amphibians living in Tasmania during the Early Triassic Period (Fig. 9.32). Similar types of creatures are found in rocks of the same age in Antarctica, South America and South Africa. This provides good evidence that the continents were then joined together.

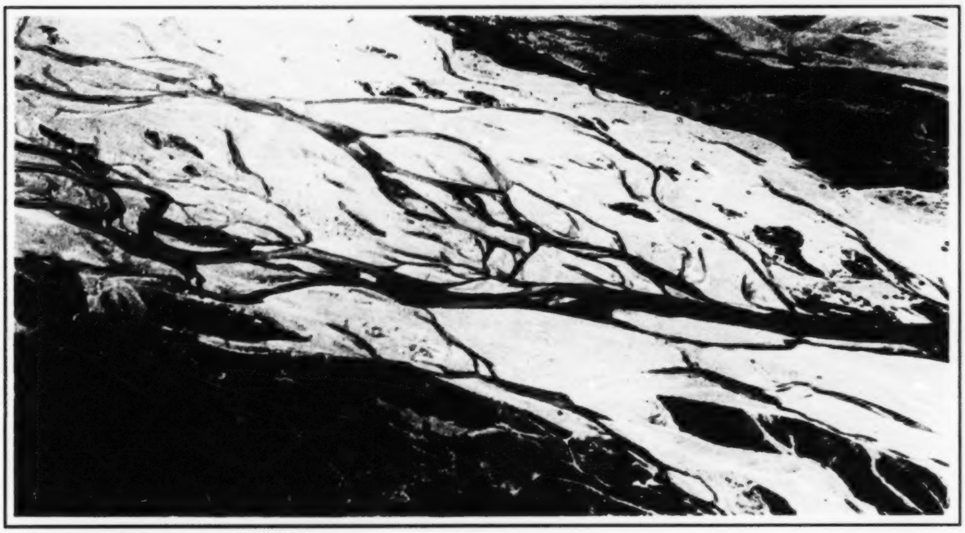


*Fig. 9.31:
A braided stream.*

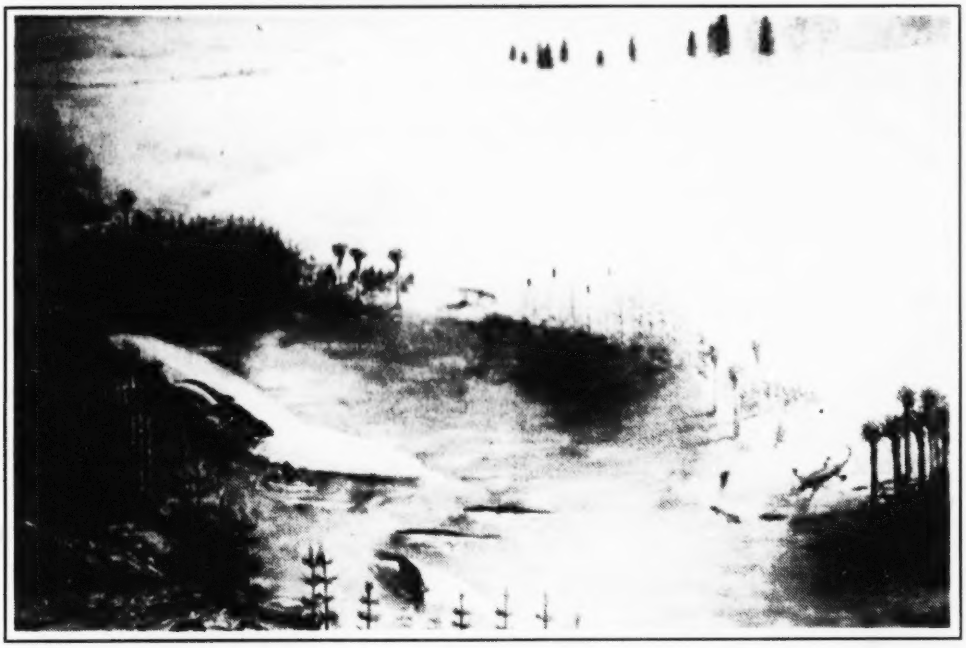


*Fig. 9.32:
A reconstruction of an Early Triassic stream community.*

Fig. 9.33: Ginkgo.

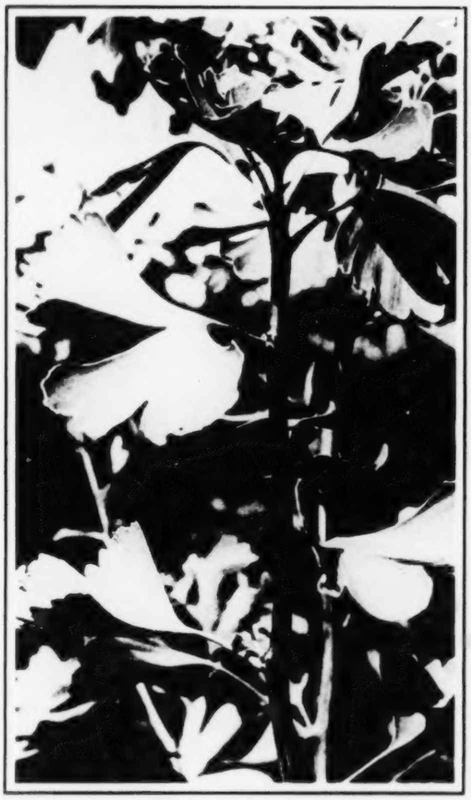
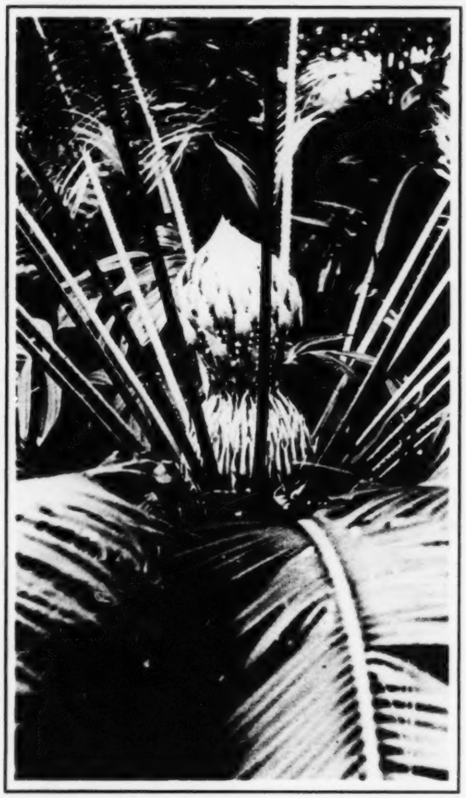


Fig. 9.35: A cycad.



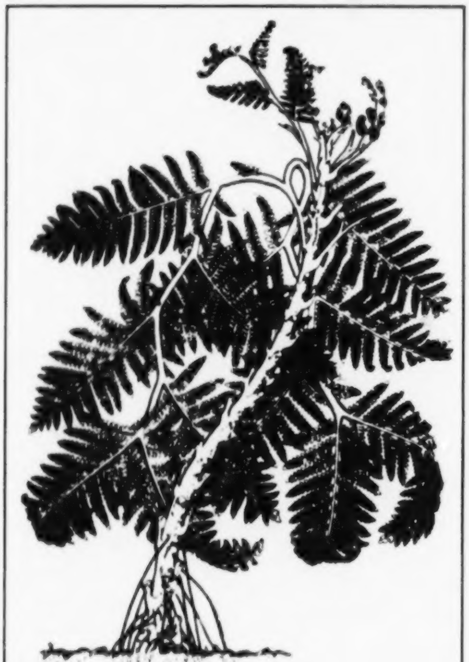


Fig. 9.34: A seed fern (now extinct).

As time progressed, streams carried more mud than sand. Rivers meandered snakelike across the flood plains. The vegetation, consisting of rushes, low club mosses, conifers, ginkgos (Fig. 9.33), ferns and seed ferns (Fig. 9.34), became more abundant.

During the middle part of the Triassic Period, uplift occurred in the north-east of the State. Volcanoes erupted and basalt lavas flowed where the town of St. Marys now stands. These igneous rocks have been radiometrically dated at 230 million years. Volcanic rhyolite near Bicheno has been dated at 215 million years.

The seasonal rainfall of the Early Triassic Period had been replaced by consistently high rainfall. Plants were abundant and included large club mosses and cycads (Fig. 9.35). The flood plains contained many swamps and were dotted by small cone-shaped volcanoes. In the swampy areas plant matter built up and was eventually turned into coal. Coal mining currently takes place near Fingal and other large reserves await development.

The great invasion (200 million to 160 million years ago)

There is no record of events in Tasmania from 200 million years ago till the rather dramatic occurrences of 165 million years ago. It was about then that the southern super-continent, Gondwana, began to split in two. We were a considerable distance from the initial split but it nevertheless triggered a large-scale melting of upper mantle and possibly lower crust beneath Tasmania.

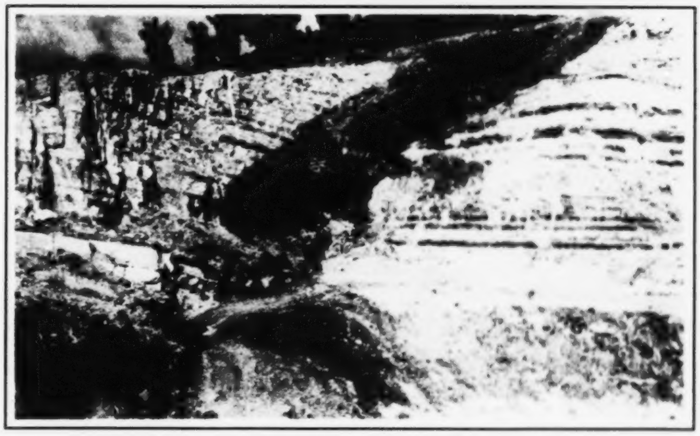
Times would have been very traumatic for any dinosaurs roaming the Jurassic surface. The land was uplifted as magma rose through cracks in the crust. Earthquakes were frequent and very violent. The north-west-trending Tiers Fault elevated the rocks of the Central Plateau by some 600 metres.

In the middle parts of the crust the molten material intruded as cone-shaped structures (Fig. 9.36). Where it reached the flat-lying Permian and Triassic sediments it forced its way between the layers to form large sills (up to 450 metres thick) and smaller cross-cutting dykes (Fig. 9.37). The magma cooled to form the dark-coloured igneous rock dolerite.

Vertical joints or lines of weakness, the result of shrinkage when cooling and/or later earthquake activity, occur in many of the sills. They are responsible for the appearance of Mount Wellington's Organ Pipes. The wide spacing of the joints and tough nature of the dolerite make it very resistant to erosion. Dolerite has been uncovered over much of Tasmania, and now caps many of the State's high areas (Fig. 9.38).

The magma may have reached the surface to form basalt near Lune River, in the south of the State.

Fig. 9.37: A dolerite dyke cutting horizontal Permian sediments (Mount Nelson, Hobart).



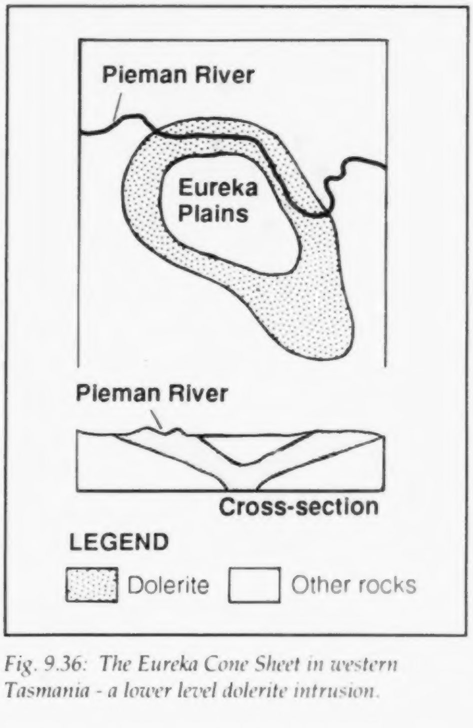

Pieman River
Eureka Plains
Pieman River
Cross-section
LEGEND
▨ Dolerite
☐ Other rocks

Fig. 9.36: The Eureka Cone Sheet in western Tasmania - a lower level dolerite intrusion.

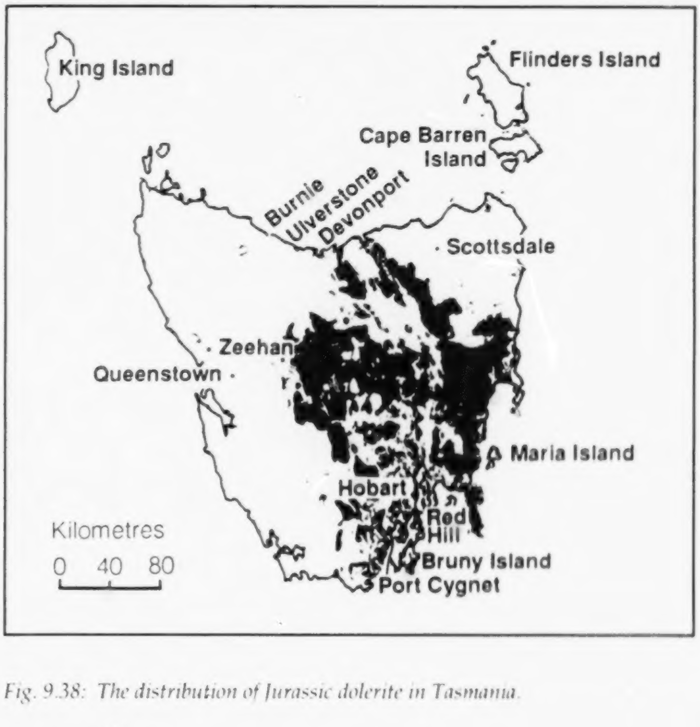

King Island
Flinders Island
Cape Barren Island
Burnie
Ulverstone
Devonport
Scottsdale
Zeehan
Queenstown
Maria Island
Hobart
Red Hill
Bruny Island
Port Cygnet
Kilometres
0 40 80

Fig. 9.38: The distribution of Jurassic dolerite in Tasmania.

Chapter nine

Tasmania takes shape (160 million to 55 million years ago)

The Tasmanian crust was stretched during the dolerite invasion. This stretching has continued on and off till the present day, causing earthquakes and large horst and graben structures (Fig. 9.39).

Fig. 9.39: Horsts, grabens and normal faults.

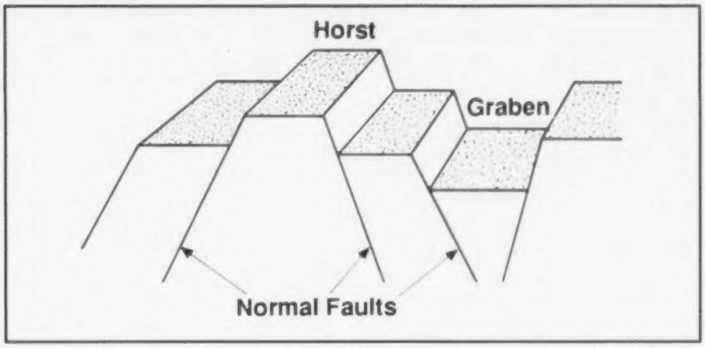
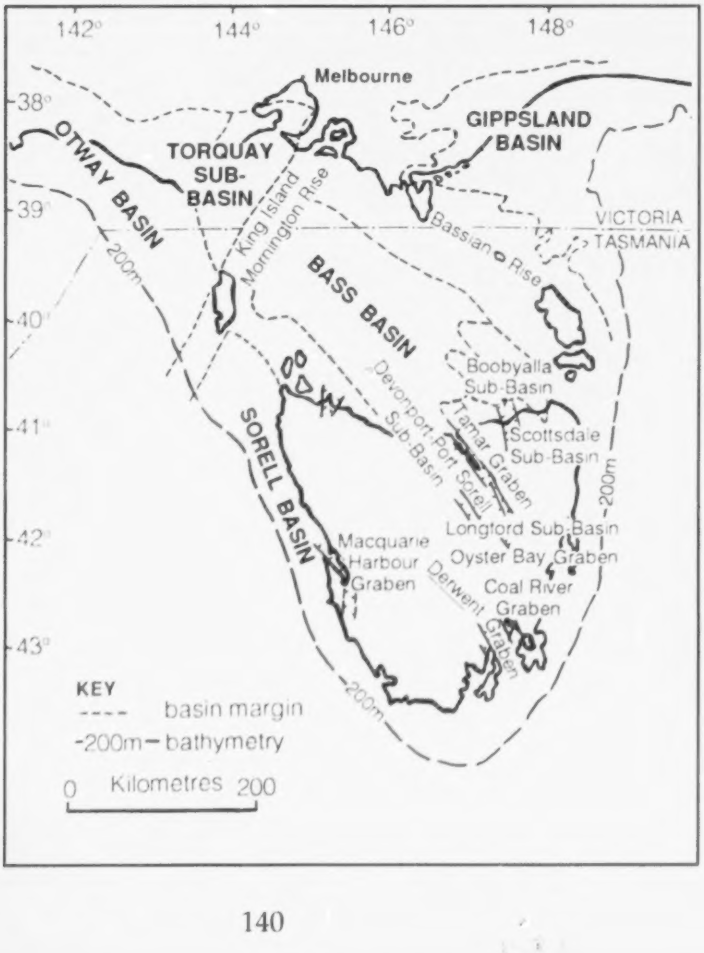

Horst
Graben
Normal Faults

Fig. 9.40: Locality map showing major structural features.


142°
144°
146°
148°
38°
39°
40°
41°
42°
43°
Melbourne
GIPPSLAND BASIN
TORQUAY SUB-BASIN
OTWAY BASIN
King Island
Mornington Rise
VICTORIA
TASMANIA
Bassian Rise
BASS BASIN
200m
Boobyalla Sub-Basin
Devonport-Port Sorell Sub-Basin
Tamar Graben
Scottsdale Sub-Basin
SORELL BASIN
200m
Longford Sub-Basin
Macquarie Harbour Graben
Oyster Bay Graben
Coal River Graben
Derwent Graben
200m
KEY
---- basin margin
-200m- bathymetry
0 Kilometres 200

About 140 million years ago north-west-trending faults and crustal sinking (subsidence) formed the Bass Basin (Fig. 9.40) and shaped Tasmania's north coast. Erosion of high areas provided clay, sand and gravel for deposition in the rivers and lakes that occupied what is now Bass Strait.

Nearly 100 million years ago igneous activity produced small sills and dykes (Fig. 9.41) near Cygnet and in north-eastern Tasmania. Volcanic material of the same age occurs at Cape Portland. At the same time faulting formed a graben at Boobyalla (Fig. 9.40). This faulting is related to an unconformity in Bass Basin sediments.

About 90 million years ago a large crustal fracture opened up along Tasmania's east coast. New Zealand slowly drifted away from Australia, forming the Tasman Sea.

Normal faulting and crustal subsidence spread over wide areas of present-day Tasmania at the end of the Cretaceous Period (about 70 million years ago). Old Jurassic faults were reactivated and a number of north-west-trending horst and graben structures (Fig. 9.40) were formed. These provided much of the framework for Tasmania's present land surface. The high horst areas began to erode and sediments were deposited in the lakes and river valleys that occupied the graben areas. Volcanoes began erupting along the fault-lines at the edges of the graben areas about 55 million years ago.

In the Early Tertiary Period (about 55 million years ago) the Southern Ocean started to grow and Australia began its slow northward drift away from Antarctica. The initial fracturing that shaped Tasmania's west and south coasts took place about 120 million years ago.

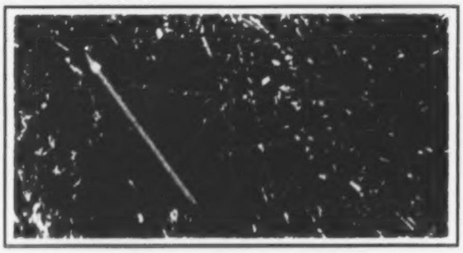


Fig. 9.41: Part of a 100-million-year-old dyke near Cygnet. The mixture of large and small crystals is caused by two phases of cooling. The rock is called a porphyry.

Moving north (55 million to 3 million years ago)

About 40 million years ago the sea flooded the full extent of the Bass Basin and has occupied at least part of the area ever since. Tiny plants and animals died, sank to the bottom and were mixed with sand and mud on the sea floor. They were buried and turned very slowly into oil and gas. No economic prospects are known in the Bass Basin, but in the north-east of Bass Strait Australia's largest oil fields supply more than half the nation's needs.

High land areas continued to supply sediment to the river valleys and lakes that occupied most of Tasmania's graben areas. Just over 20 million years ago the sea-level rose and flooded parts of the north, north-west, King Island and Flinders Island. The climate was probably sub-tropical. Fossil Bluff at Wynyard contains the remains of creatures that lived in the shallow mid-Tertiary sea.

The warm sub-tropical climate occurred at a time when Tasmania was closer to the South Pole. Tasmania has been moving slowly north for the past 55 million years (Fig. 9.42). Warmer Tasmanian climates during this period probably reflect much warmer climates for the Earth as a whole.

During these sub-tropical conditions, weathering produced soils rich in the oxides of iron and aluminium (laterite and bauxite). Small deposits of these materials can be found near Launceston.

Sediment continued to fill the graben depressions. In the north-east rivers flowed into the Bass Basin and deposited tin-rich sediments along their course. Large lakes occupied many graben areas and rainforest vegetation covered parts of the State.

Volcanoes continued to erupt along the fault-lines at the graben edges. Volcanoes erupted throughout the Tertiary Period with a maximum level of activity about 22 million years ago.

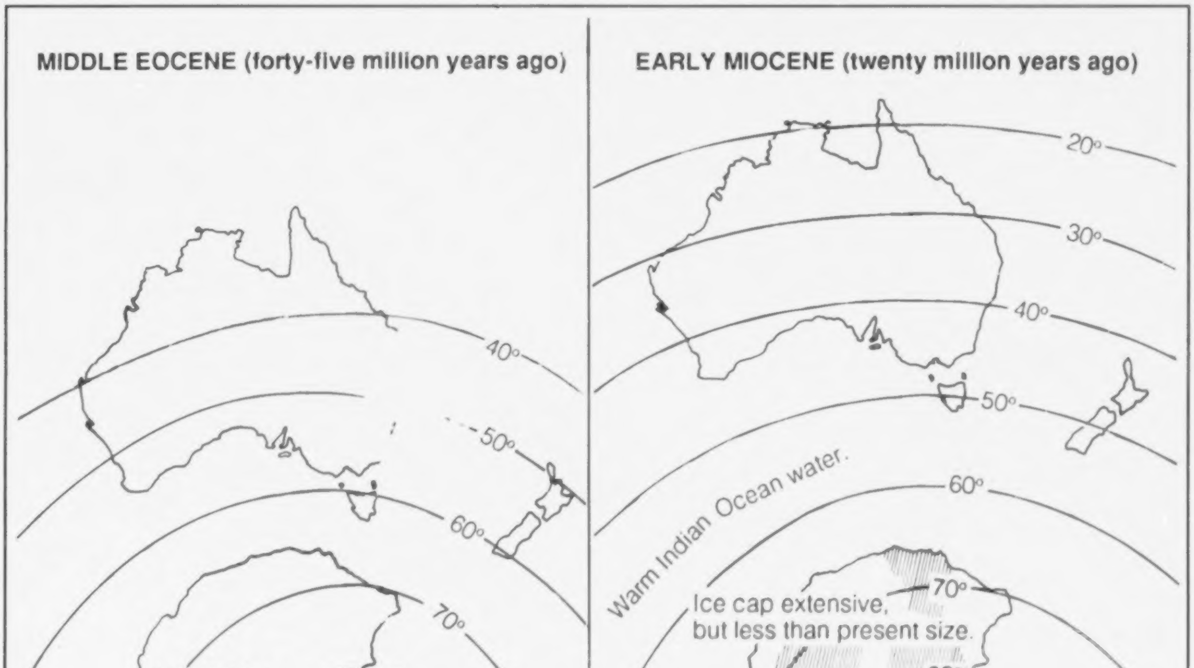

MIDDLE EOCENE (forty-five million years ago)
40°
50°
60°
70°
80°
Limited ice development?
+ South Pole
EARLY MIOCENE (twenty million years ago)
20°
30°
40°
50°
60°
70°
80°
Warm Indian Ocean water.
Ice cap extensive, but less than present size.
+ South Pole

Fig. 9.42: Continental drift during the Tertiary.

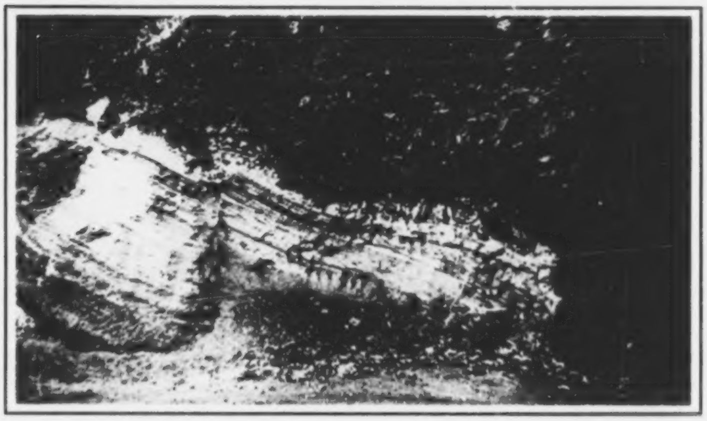


Fig. 9.44: An example of Tertiary basalt overlying Tertiary lake sediments at Plenty.

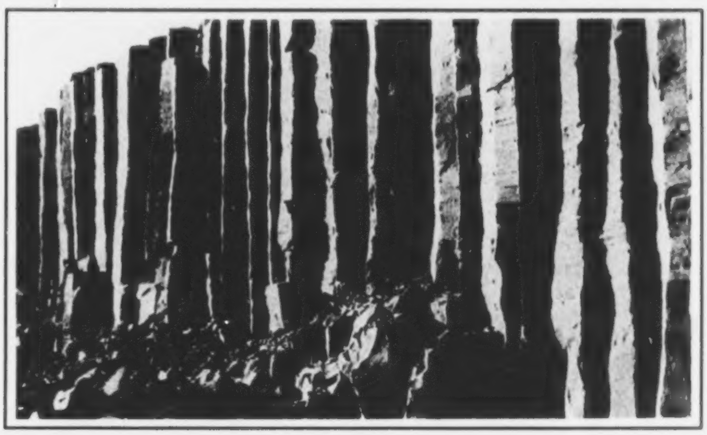


Fig. 9.45: Vertical joints in Tertiary basalt near Great Lake.

Fig. 9.46: A landslip on a basaltic hill near Lillico.

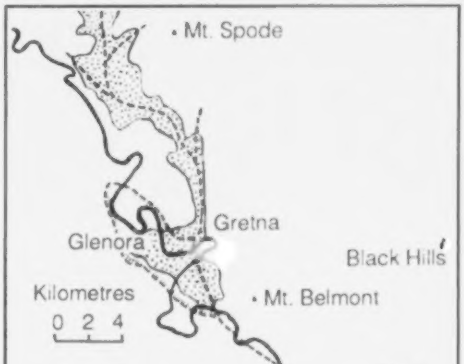
The hot, runny, basalt lava flowed down river courses, burying the tin-rich sediments, or deep-leads, in north-eastern Tasmania. Old river channels and ancient lakes were filled with lava in many parts of the State. The height of the base of the basalt provides information about the Tertiary topography (Figs. 9.43 and 9.44).

As the lavas cooled, prominent vertical joints developed (Fig. 9.45). The high degree of jointing, together with the large number of gas bubbles and the composition of the rock, make it very susceptible to weathering. Basalt lavas are particularly abundant in north-western Tasmania and the Bass Basin. As a result, deep, rich soils have developed across the north-west and make it the State's most important agricultural area. Problems can arise when this land is cleared on steep slopes and heavy spring rains cause slumping (Fig. 9.46).

Several distinct lava flows can be seen in some areas. Volcanic ash buried a forest near Bushy Park. On Hobart's eastern shore a hot spring deposit, covered by lava, preserved Australia's oldest marsupial remains.

The Australian plate (including New Guinea and Tasmania) continued to move north. About 10 million years ago the Earth's climate cooled. Ice-sheets expanded across Antarctica and the sea-level dropped.

Fig. 9.43: Drainage of the Derwent River before and after basalt laval flows.



Changing climate (the last 3 million years)

About three million years ago, when our early ancestors were evolving in Africa, an Ice Age began in Tasmania. The Earth's recent history has been dominated by dramatic changes in climate. At least three main episodes of glaciation occurred in Tasmania:

- 3 to 1.5 million years ago;
- 190,000 to 130,000 years ago;
- 75,000 to 12,000 years ago.

Ice Ages can be recognised by the erosion features and deposits left behind by ice. Fossils, particularly of plants, can also provide clues about past changes in climate. Lake sediments contain pollen from vegetation growing nearby. As the climate changes, plants more suited to the new environment begin to grow. Pollen can be obtained from the different layers of lake sediment. Any carbon present can be used to provide a radiometric date for deposits up to 50,000 years old.

The last glaciation was very severe and obliterated much of the evidence from previous episodes. The amount of weathering on dolerite boulders, in rubble dumped by ice, has been used to infer older periods of glaciation. In some areas (for example, the Henty River) old ice deposits are overlain by newer, less weathered material also dumped by ice.

About 20,000 years ago ice covered all the higher areas in Tasmania and glaciers flowed down the upper parts of most river valleys (Fig. 9.47). The ice carved out deep U-shaped depressions (Fig. 9.48).

At the ends of the glaciers large mounds of boulders and clay were dumped by the melting ice. Some of these mounds, or moraines, now dam highland lakes (Fig. 9.49).

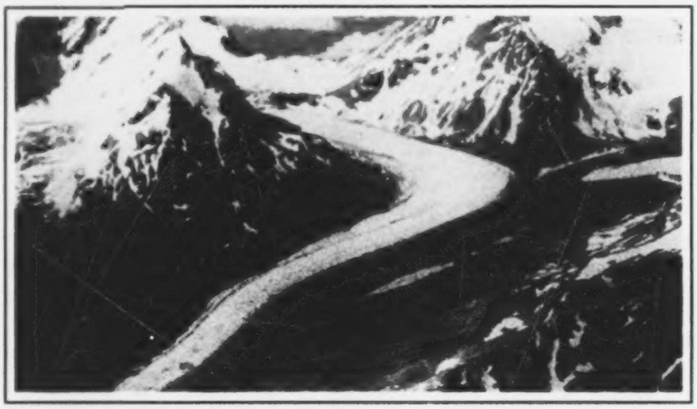


Fig. 9.47: A valley glacier flowing down from snow-covered mountains.

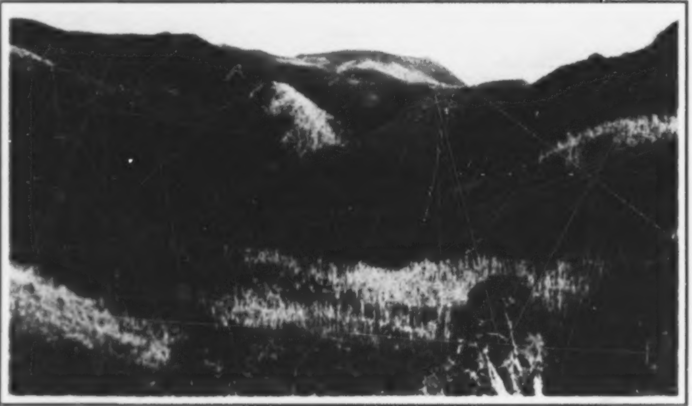


Fig. 9.48: A deep U-shaped valley carved by a glacier—the Surprise Valley, Lyell Highway.

Fig. 9.49: Lake Seal, Mount Field National Park —the lake is dammed by a glacial moraine.

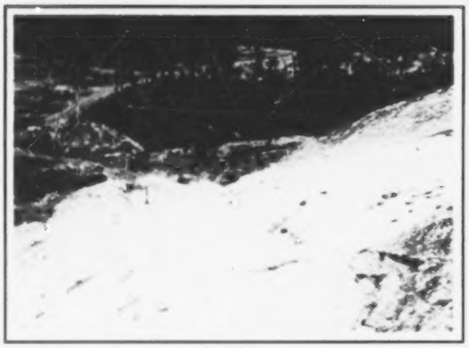


Fig. 9.50: Grooved, scratched and polished rock near Rowallan Dam site on the Mersey River.

Further up the valley and across the higher plateau areas the ice flow scratched, grooved and polished the underlying rock (Fig. 9.50).

In areas not affected by glaciers water seeped into cracks and joints in the rock. At night the water froze and expanded. This enlarged the joints. Repeated freezing and thawing broke off blocks of rock and slowly moved them downhill in large block streams (Fig. 9.51).

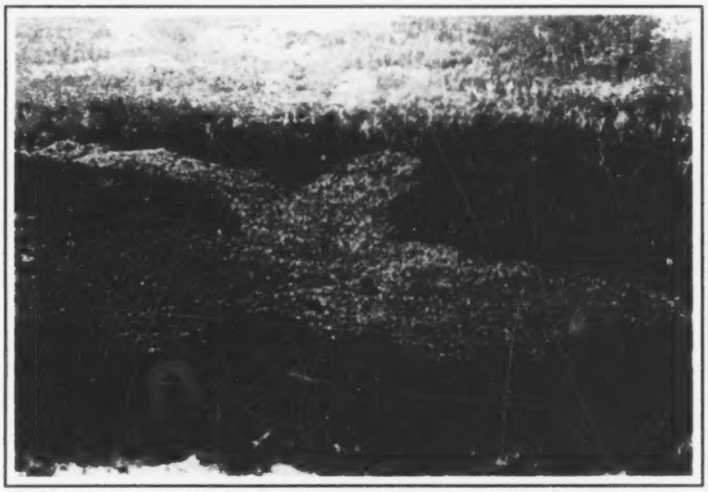


Fig. 9.51: A block stream.

Variations in the levels of land and sea

During an Ice Age the sea-level drops. When the climate warms up ice-sheets melt and the sea-level rises again. Before the last glaciation the sea was probably five metres higher than present. In north-eastern Tasmania marine sediments of this age have been found at a height of 30 metres above sea-level. This suggests that parts of north-eastern Tasmania must have risen at least 25 metres in the last 100,000 years. Figure 9.52 shows a wave-cut shoreline produced by the action of waves when the sea was higher or before the island was uplifted. Very recent movements have occurred along old fault lines in other parts of Tasmania. Figure 9.53 shows a cliff produced by earthquakes along the Lake Edgar Fault in the south-west of the State.

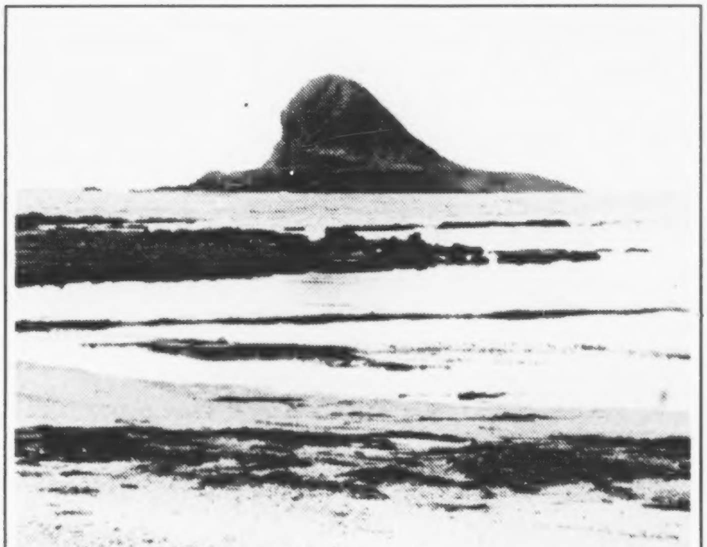


Fig. 9.52: A wave-cut platform three to four metres above present sea-level — Pyramid Island, western Tasmania.

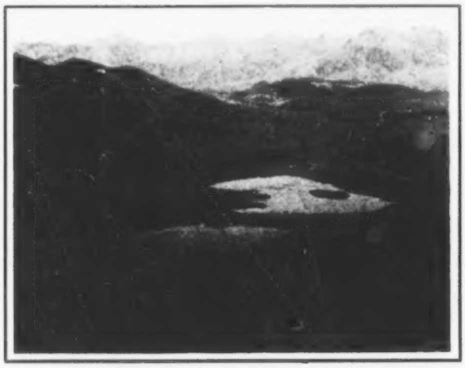


Fig. 9.53: The Lake Edgar Fault viewed from the air.

The first Tasmanians

Aborigines have lived in Tasmania for at least 23,000 years. During the last Ice Age variations in climate produced rises and falls in sea-level. Each fall left a land-bridge connecting the mainland to Tasmania through Flinders Island (Fig. 9.54). Aborigines used this land-bridge to migrate into Tasmania — possibly between 39,000 and 32,000 years ago.

The first Tasmanians lived in a very harsh environment. They took shelter in coastal and inland caves.

Aborigines living in caves along the Franklin River would have looked out on to ice-capped mountains (Fig. 9.55). Open mountain vegetation and grasslands covered much of the State. Strong westerly winds hollowed out depressions called lunettes. Two large examples are Lake Tiberias and Lake Dulverton near Oatlands. Large marsupials (Fig. 9.56) survived until the climate warmed about 12,000 years ago.

Tasmania has been an island for the last 12,000 years or so. The cool temperate conditions enabled the spread of rainforest vegetation (Fig. 9.57) over much of western Tasmania. Aborigines used fire to provide open conditions suitable for hunting. They are indirectly responsible for the wide distribution of eucalypt forest (the basis of our forestry industry) and the open Midlands region (an important agricultural area). Aborigines were Tasmania's first miners, digging iron oxide (red ochre) at places like Mount Roland for use as a cosmetic and as an item of trade.

Fig. 9.55: The type of environment surrounding Kutikina Cave when Aborigines lived there 20,000 years ago.

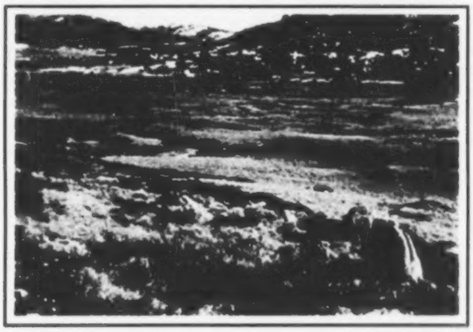
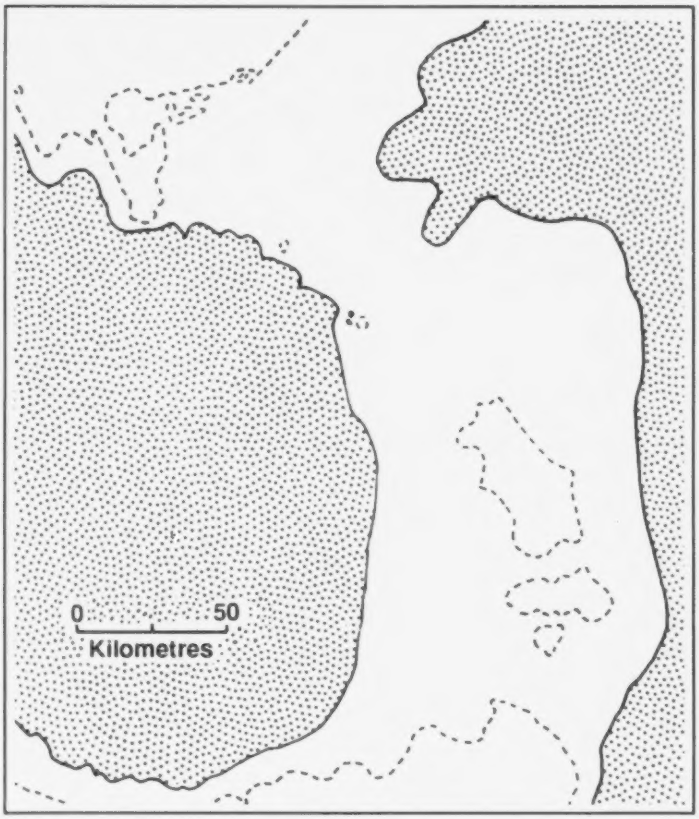


Fig. 9.54: The land-bridge used by Aborigines to cross into Tasmania about 35,000 years ago.



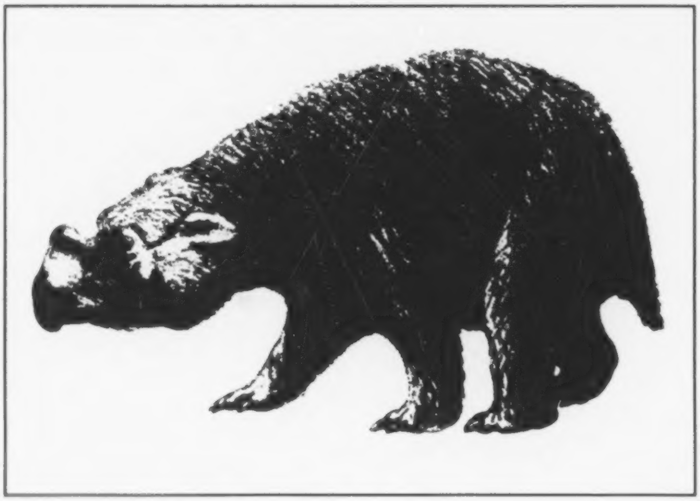


Fig. 9.56: Zygomaturus, a large marsupial rhinoceros that lived in Tasmania during the Ice Age.

Fig. 9.57: Cool temperate rainforest, widespread between the Ice Ages.

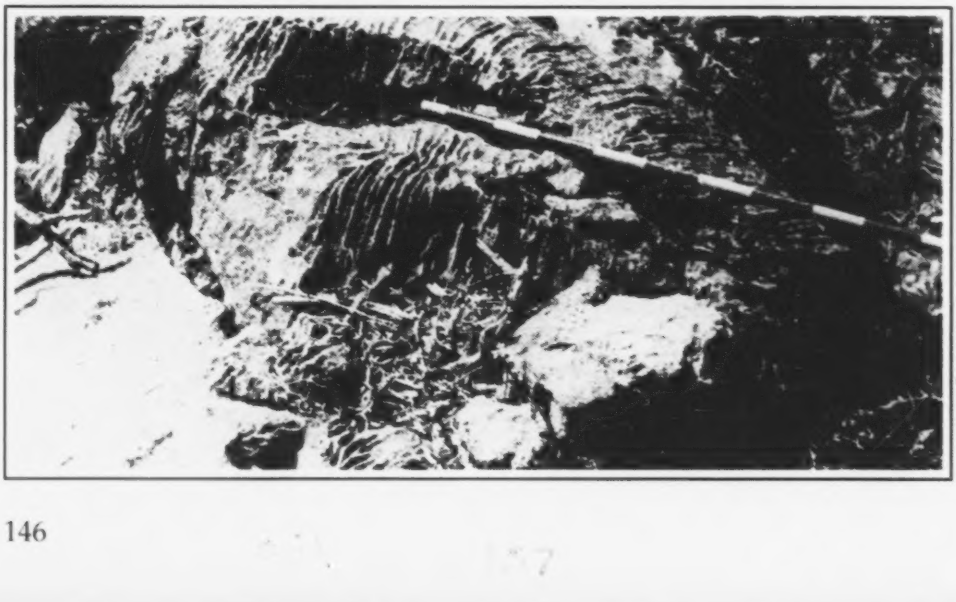
Geological change continues

Erosion continues to cut back the land surface. Heavy rainfall washes away weathered particles and dissolves soluble rock such as limestone (Fig. 9.58). Near Maydena running water flows into depressions in limestone at places like Growling Swallet and re-emerges 700 metres lower and many kilometres away at the Junee Rising. This area contains some of the longest and deepest caves in the world. Water dripping from the ceilings of caves at Mole Creek has slowly formed magnificent decorations (Fig. 9.59).

Rivers continue to carry sediment from high areas to low areas. Repeated flooding over thousands of years has produced rich alluvial soils — suitable for a variety of farming practices. Sediment that reaches the sea is transported around our coastline to form beaches and a range of other features. Winds build up sand dunes and waves attack coastal headlands to produce caves, arches (Fig. 9.60) and blowholes.

European settlement began in 1803. Today the geological riches formed during one billion years of Tasmanian history make a major contribution to the economic well-being of the State's 450,000 inhabitants.

Fig. 9.58: Rillen Karren —solution patterns in limestone made by rainwater, Mole Creek.



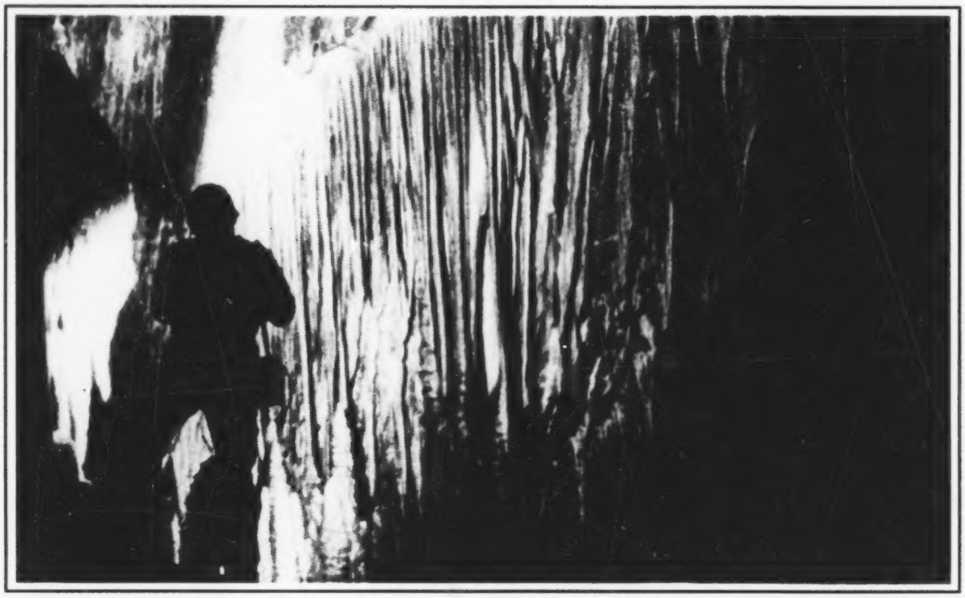


Fig. 9.59: Cave decorations, Mole Creek.

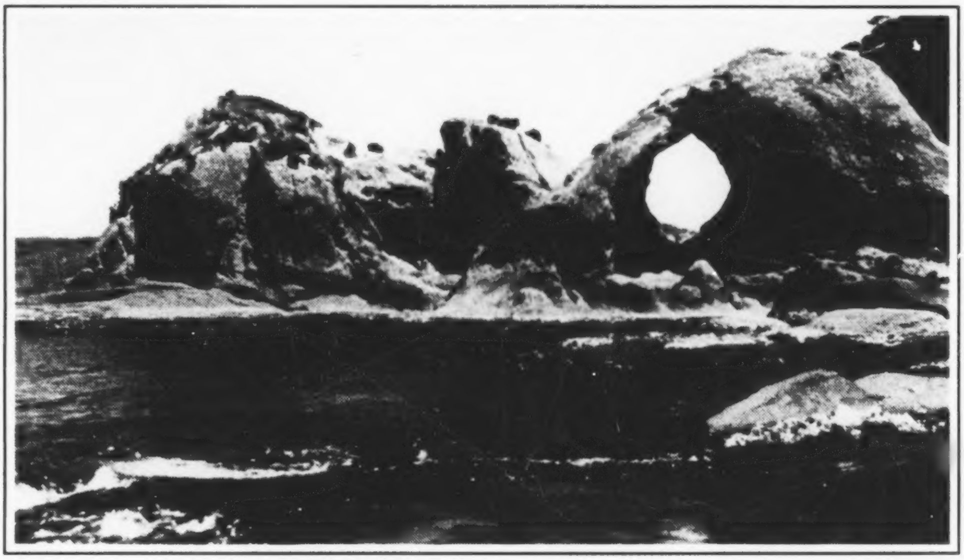


Fig. 9.60: An arch cut in granite, Maria Island.

Appendix

— Summary of the geological history of Tasmania

	Millions of years before present	Sedimentary environments	Igneous activity	Crustal movements and metamorphism	Events of economic interest
Changing climate	0 2	↑ Ice Ages ↓ erosion of high areas, deposition in low areas			
Moving north	10	cooling of climate		less frequent earthquakes	
		marine sediments in Bass Basin and north-western Tasmania sea floods Bass Basin	widespread lava flows from basalt volcanoes along graben fault-lines		oil and gas in Bass Basin (not developed) tin-rich sediments brown coal deposited in grabens
	50	sediments deposited in lakes and rivers occupying grabens		Australia begins to drift north	
Tasmania takes shape		erosion of high areas		earthquakes	
				faulting and subsidence produce horsts and grabens	
	100		minor intrusions and some volcanic activity		
		river sediments deposited in Bass Basin		faulting and subsidence forms the Bass Basin	
The Great Invasion		long period of erosion	widespread intrusion of dolerite sills and dykes	faulting and uplift associated with dolerite intrusions	

	Millions of years before present	Sedimentary environments	Igneous activity	Crustal movements and metamorphism	Events of economic interest
	200	flood plains, swamps, coal and mud, increasing rainfall braided streams and sand in a land environment	volcanoes (mainly basalt) producing lava and ash		large coal deposits form (particularly in north-eastern Tasmania)
Icebergs and swamps	250	quiet lagoonal environments			
		brief period of non-marine deposition			
		sea invades large areas — mud deposited on sea floor (fossils)			deposits oil shale form in the north of the State
		ice-sheet covers much of Tasmania			
	300			Tasmania near the South Pole	
		erosion slowly cuts back high areas		north-eastern and western Tasmania move together along the Tamar Fracture System	
Folds, melts and tin					
			widespread intrusions of granite magma	major mountain building episode, folding	tin, tungsten and minor silver, lead, zinc and gold mineralisation associated with granite

	Millions of years before present	Sedimentary environments	Igneous activity	Crustal movements and metamorphism	Events of economic interest
	400	deposits of sand and mud deep water muds deposited in what is now north-eastern Tasmania			
Quiet times		(abundant fossils) carbonate mud on the sea floor		Tasmania near the equator	limestone (mined for various purposes)
		mud and sand deposited in shallow seas			
	500	high areas eroded, river gravels (alluvial fans) deposited at the base of the slopes		uplift to form mountain areas	
		mud, silt and turbidite deposits accumulate in troughs (trilobite fossils)	a chain of volcanoes along the eastern edge of the Dundas Trough produce large quantities of lava and ash		large sulfide deposits rich in copper, lead, zinc, gold and silver settle on the sea floor
Fire and water				squeezing forces big chunks of serpentine up into overlying sediments	osmiridium, chromite and minor nickel mineralisation associated with serpentine
	550				

	Millions of years before present	Sedimentary environments	Igneous activity	Crustal movements and metamorphism	Events of economic interest
		mud and turbidite deposits accumulate in troughs		earthquakes	
Fire and water	600		basalt pillow lavas form on the sea floor	cracks develop in the crust beneath the troughs	
	650	carbonate sediment deposited on the sea floor of the troughs (stromatolite fossils)		stretching and earthquakes produce narrow troughs	
			dolerite dykes intrude the Arthur Lineament	folding, faulting and metamorphism (particularly in the Arthur Lineament)	Savage River iron ore deposits form on sea floor
	700	erosion of high areas, mud and sand deposited in shallow areas			
The first rocks	800			uplift, folding and metamorphism (?)	
	900				
	1000	sand and clay washed into a shallow sea from a nearby desert			

Bibliography

Ahmad, N., Bartlett, H.A. and Green, D.H. (1959) 'The Glaciation of the King Valley, Western Tasmania', *Pap. Proc. Royal Soc. Tas.*, 93: 11-16.

Anand Alwar, M.A. (1960) 'Geology and Structures of the Middle Derwent Valley' *Pap. Proc. Royal Soc. Tas.*, 94: 13-24.

Augustinus, P. and Colhoun, E.A. (1986) 'Glacial History of the Upper Pieman and Boco Valleys, Western Tasmania', *Australian Journal of Earth Sciences*, 33: 181-191.

Bagnold, R.A. (1941) *The Physics of Blown Sand, Desert Dunes*, Methuen.

Baker, W. and Ahmad, N. (1958) 'A Re-examination of the Fiord Theory of Port Davey, Tasmania', *Pap. Roy. Soc. Tas.*, 92.

Banks, M.R. (1962) 'Cainozoic System' in Spry, A., and Banks, M.R.,'The Geology of Tasmania', *Journal Geological Society Australia*, 9: 2.

Banks, M.R. (1965) 'Geology and Mineral Deposits', *ANZAAS Atlas of Tasmania.*, Lands and Survey Department, Hobart.

Banks, M.R. (ed.) (1973) *The Lake Country* , Royal Society of Tasmania.

Banks, M.R. (1978) *Foundations of Our Scenery* Tasmania Media Centre, Education Department of Tasmania, Hobart.

Banks, M.R., Colhoun, E.A. and Chick, N.K. (1977) ' A reconnaissance of the geomorphology of central western Tasmania', in Banks, M.R. and Kirkpatrick, J.B. (eds.) *Landscape and Man* , Royal Society of Tasmania.

Banks, M.R., Cosgriff and Kemp (1978) 'A Tasmanian Triassic stream community', *Australian Natural History.*

Barbetti, M. and Colhoun, E.A. (1988) 'Reversed Magnetisation of Glaciolacustrine Sediments from Western Tasmania', *Search*: 19(3) 151–153.

Binks, C.J. (1980) *Explorers of Western Tasmania,* Mary Fisher Bookshop, Launceston.

Bird, E.C.F. (1965) 'Sediment Supply to Sand and Shingle Beaches', Abstract, *ANZAAS. 38th Congress* Sect. P.

Bloom, A. (1969) *The Surface of the Earth,* Prentice-Hall.

Boulter (1978) 'Geology' in Gee, H. and Fenton, J. (eds.) *The South West Book* , Australian Conservation Foundation, Melbourne.

Bowden, A.R. (1981)*Coastal sands of northeastern Tasmania: geomorphology and groundwater hydrology.* PhD Thesis, University of Tasmania, (Unpub.).

Bowden, A.R. (1983) 'Relict terrestial dunes: legacies of a former climate in coastal northeastern Tasmania', *Z. Geomorph. N.F.*, 154-174.

Bowden, A.R. and Colhoun, E.A. (1984) 'Quaternary Emergent Shorelines of Tasmania', *Coastal Geomorphology in Australia,* Thom, B.C. (ed.), 14: 313-341.

Bradley, J. (1954) 'The Geology of the West Coast Range of Tasmania, Pt. 1', *Pap. Proc. Royal Soc. Tas.*, 88: 192-243.

Bradley, R.S. (1984) *Quaternary Paleoclimatology* , Allen & Unwin.

Bunton, S. and Eberhard, R. (1984) *Vertical Caves of Tasmania* , Adventure Presentations.

Burrett, C.F. and Martin, E.L. (eds.) (1989) *Geology and Mineral Resources of Tasmania,* Geological Society of Australia Inc.

Caine, N. (1983) *The Mountains of North-eastern Tasmania*, Balkema.

Calver and Castledon (1981) 'Triassic basalts from Tasmania', *Search* , 12, 1-2.

Carey, S.W. (1947) 'Geology of the Launceston District', *Rec. Queen Victoria Mus.*, II: 31-46.

Carey, S.W. (1960) *Tasmanian University Seismic Net*, Department of Geology, University of Tasmania.

Carey, S.W. (1962) 'Scale of Geotechnic Phenomena', *Journal. Geol. Soc. India*, 3: 97-105.

Carey, S.W. (1970) 'Australia, New Guinea and Melanesia in the current revolution in concepts of the evolution of the earth', *Search*, 1: 178-189.

Carey, S.W. (1981) 'Notes to accompany the photo-interpretation of the country between the Arthur and Pieman Rivers, Tasmania', Tas. Dept. Mines Open File Rep. 82-1753.

Carey, S.W. and Banks, M.R. (1954) 'Lower Palaeozoic unconformities in Tasmania', *Pap. Proc. Royal Soc. Tas.*, 88: 245-269.

Chick, N.K. (1971) 'Fossil structures of the Ulverstone District, Tasmania', *Pap. Proc. Royal Soc. Tas.*, 105: 29-40.

Chorley, R.J., Schumm, S.A. and Sugden, D.E. (1984) *Geomorphology* , Methuen.

Clark, I.F. and Cook, B.J. (1983) *Perspectives of the Earth*, Australian Academy of Science, Canberra.

Clarke, M.J. and Farmer, N. (1976) 'Biostratigraphic Nomenclature for Late Palaeozoic Rocks in Tasmania', *Pap. Proc. Royal Soc.Tas.*, 110: 91-109.

Colclough, J. (1964) 'Soil Conservation and soil erosion control in Tasmania', *Tas. Journal Agric.*

Colclough, J. (1970) 'Background to Tasmanian soil erosion', *Tas. Journal Agric.*

Colhoun, E.A. (1975) 'A Quaternary climatic curve for Tasmania', in Australasian Conference on Climate and Climatic Change, *R. Meteor. Soc.*: 40pp.

Colhoun, E.A. et al. (1979) 'Quaternary Excursion to Northwest and West Tasmania: Field Guide', Department of Geography, University of Tasmania, 50pp.

Colhoun, E.A. (1980) 'Glacial Diversion of Drainage: An Example from the Cradle Mountain National Park, Northern Tasmania,' *Aust. Geographer*, Vol. 14 pp. 365-367.

Colhoun, E.A. (1983) 'Tasmanian Sea levels in the last 15,000 years' in *Australian Sea levels in the last 15,000 years: a review*, Hopley, D. (ed.), Monograph Series Occasional Paper 3, Department of Geography, James Cook University.

Colhoun, E.A. (1985) 'Glaciation of the West Coast Range, Tasmania', *Quaternary Research* 24(1): 39-59.

Colhoun, E.A. and Moon, A. (1984) 'Estuarine Sediments at the Bowen Bridge on the Derwent River, Southeastern Tasmania', *Search* 15 (7-8), 224-226.

Collins, P.L.F. (1981) 'The geology and genesis of the Cleveland tin deposit, Western Tasmania', *Economic Geology* , 76: 365-392.

Collins, P.L.F. and Williams, E. (1986) 'Metallogeny and tectonic development of the Tasman Fold Belt System in Tasmania', *Ore Geology Reviews*, 1: 153-201.

Collinson, J.D. (1978) 'Alluvial sediments', in Reading, H.G. (ed.), *Sedimentary Environments and Facies*, Elsevier.

Cooper, R.A. and Grindley, G.W. (eds.) (1982) 'Late Proterozoic to Devonian sequences of South-eastern Australia, Antarctica and New Zealand and their correlation', *Special Pub. No. 9* , Geological Society of Australia.

Corbett, K.D. (1981) 'Stratigraphy and Mineralisation in the Mt Read Volcanics, Western Tasmania', *Economic Geology* 76: 209-230.

Corbett, K.D. and Lees, T.C. (1987) 'Stratigraphic and structural relationships and evidence for Cambrian deformation at the western margin of the Mt. Read Volcanics, Tasmania', *Australian Journal of Earth Sciences*, 34: 45-67.

Cotton, C.A. (1949) *Geomorphology: an Introduction to the Study of Landforms*, Whitcombe and Tombs.

Cromer, W.C. (1979) 'Results of drilling for water in the Devonport — Port Sorell — Sassafrass area, 1967-1979, and selection of future bore sites', *Tas. Dept. Mines Unpubl. Report*, 1979/16.

Davies, J.L. (1957) 'The importance of Cut and Fill in the Development of Sand Beach Ridges', *Aust. Journ. Sci.*, 20. No. 4: 105-111.

Davies, J.L. (1958a) 'The Cryoplanation of Mount Wellington', *Pap. Royal Soc. Tas.*, 92: 151-154.

Davies, J.L. (1958b) 'Wave Refraction and the Evolution of Shore Line curves', *Geog. Studies*, 5, No. 2: 1-4.

Davies, J.L. (1959) 'Sea Level Change and Shoreline Development in South-Eastern Tasmania', *Pap. Proc. Royal Soc. Tas.*, 93: 89-95.

Davies, J.L. (1960) 'Beach alignment in southern Australia', *Aust. Geographer*, 8, No.1: 42-44.

Davies, J.L. (1961) 'Tasmanian Beach Ridge Systems in Relation to Sea Level Change', *Pap. Royal Soc. Tas.*, 95: 35-40.

Davies, J.L. (1962) 'Cainozoic System — geomorphology and glaciation in the geology of Tasmania', *Journal Geological Soc. Aust.* 9,2.

Davies, J.L. (1967) 'Tasmanian Landforms and Quaternary Climates' in *Landform Studies from Australia and New Guinea* Jennings, J.N. and Mabbutt, J.A. (eds.), Cambridge University Press.

Davies, J.L. (1972) *Landforms of Cold Climates*, Australian National University Press, Canberra.

Davies, J.L. (1978) 'Beach sand and wave energy in Tasmania' in Davies and Williams (eds.) *Landform Evolution in Australasia*, A.N.U. Press, Canberra, 158-167.

Derbyshire, E. (1963) 'Glaciation of the Lake St. Clair District, West-Central Tasmania', *Aust. Geog.*, 9, No. 3: 97-110.

Derbyshire, E. (1971) 'The Bathymetry of Lake St. Clair, Western Central Tasmania'. *Pap. Proc. Roy. Soc. Tas.*, 105, 49-57.

Derbyshire, E., Banks, M.R. and Davies, J.L.(1965) 'Glacial Map of Tasmania', *Royal Soc. Tas. Spec. Publ. No. 2.*

Dimmock, G.M. (1957) 'The Soils of Flinders Island, Tasmania', *Soils and Land Use series, No. 23*, Division of Soils, C.S.I.R.O.

Douglas, I. (1977) *Humid Landforms* , A.N.U. Press, Canberra.

Eastoe C.J. (1979) *Geological Monuments in Tasmania* , Geological Society of Australia.

Edwards, A. B. (1941) 'The North-West Coast of Tasmania', *Pap. Proc. Royal Soc. Tas.*, 53: 233-267.

Fish, G.F. and Yaxley, M.L. (1966) *Behind the Scenery* , Education Department of Tasmania.

Fish, G.F. and Yaxley, M.L. (1972) *Geology and Landscape of Tasmania*, Jacaranda Press.

Flint, R.F. (1971) *Glacial and Quaternary Geology*, Wiley.

Flint, R.F. and Skinner, B.J. (1974) *Physical Geology* , (2nd ed.) Wiley.

Flood, J. (1983) *Archaeology of the Dreamtime* Collins.

Ford, R.J. (1956) 'Geology of the Upper Huon – Arve River Area', *Pap. Proc. Roy. Soc. Tas.*, 90: 146-156.

Ford, R. J. (1960) 'The Geology of the Fisher River Area', *Pap. Proc. Royal Soc. Tas.*, 94: 25-32.

Frakes, L.A. (1979) *Climates Throughout Geological Time*, Elsevier.

Gee, R.D. (1963) 'Structure and Petrology of the Raglan Range', *Geological Survey Bulletin, No. 47*.

Goede, A. (1965) 'Geomorphology of the Buckland Basin', *Pap. Proc. Royal Soc. Tas:* 99, 133-154.

Goede, A. (1969) 'Underground stream capture at Ida Bay, Tasmania, and the relevance of cold climatic conditions', *Aust. Geogr. Studies*. 7: 41-48.

Goede, A. (1971) 'Tasmanian Karst Areas', *Proceedings 8th Nat. Conference Aust. Speleolog. Federation*, 5-9.

Goede, A. (1974) 'The exploration history of Judd's Cavern, Cracroft Area, Tasmania' *Journal Sydney Speleolog. Soc.*, 18: 239-247.

Goede, A. (1977a) 'Cracroft expeditions – survey results, scientific observations and speculations', *Journal Sydney Speleolog. Soc.*, 18: 239-247.

Goede, A. (1977b) 'Caves and aboriginal man in Tasmania', *Proc. 11th Bienn. Conf. Aust. Speleolog. Fed.*, Canberra, 1976.

Goede, A., Murray, P. and Harmon, R. (1978) 'Pleistocene man and megafauna in Tasmania: dated evidence from cave sites', *The Artefact*, 3: 139-149.

Green, D.C. (ed.) (1982) *Geology, Mineralisation, Exploration: Western Tasmania — a symposium in honour of the late K.O. Reid*, Geological Society of Australia.

Green, G.R., Solomon and Walshe (1981) 'The formation of the volcanic–hosted massive sulphide ore deposit at Rosebery, Tasmania', *Economic Geology*, 76, 304-338.

Green, G.R. et al (1982) Submission to the Senate Select Committee, South-West Tasmania.

Griffiths, J.R. (1972) 'Australia and Gondwanaland', *Australian Natural History*, 249-253.

Gulline, A.B. (1959) 'The Underground Water Resources of the Smithton District', *Underground Water Supply Bulletin*, Paper No. 5.

Hannan, D.G. and Colhoun, E.A. (1987) 'Glacial stratigraphy of the Upper Mersey Valley, Tasmania', *Aust. Geogr. Stud.* 25(2): 36-46.

Howard, A.D. (1967) 'Drainage analysis in geological interpretation: a summation', *Bulletin of the American Association of Petroleum Geologists*, 51: 2246-2259.

Halstead, L.B. (1982) *Hunting the Past*, Hamish Hamilton.

Jennings, I.B. (1955) 'Geology of Portion of the Middle Derwent Area', *Pap. Proc. Royal. Soc. Tas.*, 89: 169-190.

Jennings, I.B. (1958) 'The Round Mount District', *Geol. Survey Bulletin*, No. 45.,Tas. Mines Dept.

Jennings, I.B., Noldart, A.J. and Williams, E. (1967) 'Geology and Mineral Resources of Tasmania', *Geol. Surv. Tas.*, No. 50.

Jennings, J.N. (1957a) 'Coastal Dune Lakes as exemplified from King Island, Tasmania', *Geog. Journal*, 1: 59-70.

Jennings, J.N.(1957b) 'On the Orientation of Parabolic or U-Dunes', *Geog. Journal*, 123: 476-479.

Jennings, J.N. (1959a) 'The Coastal Geomorphology of King Island, Bass Strait, in Relation to Changes in the Relative Level of Land and Sea', *Rec. Queen Victoria Mus.*, N.S. No. 11: 1-39.

Jennings, J.N. (1959b) 'The Submarine Topography of Bass Strait', *Proc. Royal Soc. Vic.*, 57: 49-72.

Jennings, J.N. (1971) *Karst*, Australian National University Press, Canberra.

Johnston, R.M. (1888) *Systematic Account of the Geology of Tasmania*, Government Printer, Hobart.

Kemp, E.M. (1978) 'Tertiary climatic evolution and vegetation history in the South-east Indian Ocean region', *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 24: 169-208.

Kershaw, R.C., Sutherland, F.L. (1972) 'Quaternary geomorphology of Flinders Island', *Rec. Queen Victoria Mus.*, 43.

Kiernan, K. (1980) 'Caves of Tasmania', *Caving International Magazine*, Nos. 6 & 7, 36-45.

Kiernan, K.W. (1983) 'Weathering evidence for an additional glacial stage in Tasmania', *Australian Geographical Studies*, 21(2), 197-220.

Kiernan, K.W. (1985) *Late Cainozoic glaciation and mountain geomorphology in the Central Highlands of Tasmania.*, Ph.D. Thesis, University of Tasmania.

Leaman, D.E. (1971) 'The Geology and Groundwater resources of the Coal River basin', *Tas. Dept. Mines Tech. Report*, 11: 67-68.

Leopold, L. (1953) 'Downstream Change of Velocity in Rivers', *American Journal Science*, 251: 606-624.

Leopold, L. and Langbein, W. (1966) 'River Meanders', *American Journal Science*, 214: 6.

Linton, D.L. (1964) *The Forms of Glacial Erosion*, Presidential Address 1963 Institute of British Geographers.

MacPhail, M.K. (1975) 'Late Pleistocene environments in Tasmania', *Search* , 6, 7.

McKenzie, D.P. and Richter, F. (1976) 'Convection Currents in the earth's mantle', *Scientific American*, 235: 72-89.

McKerrow, W.S. (ed.) (1978) *The Ecology of Fossils*, M.I.T. Press.

Matthews, W.L. (1983) 'Geology and groundwater of the Longford Tertiary basin', *Bull. Geol. Surv. Tasm.* , 59.

Moore, W.R., Baillie, P.W., Forsyth, S.M., Hudspeth, J.W., Richardson, R.G. and Turner, N.J. (1984) 'Boobyalla Subbasin: a Cretaceous onshore extension of the southern edge of the Bass Basin', *Journal Aust. Pet. Explor. Assoc.* 24: 110-117.

Morisawa, M. (1968) *Streams: their dynamics and Morphology*, McGraw Hill.

Murray, P. and Goede, A. (1977) 'Pleistocene vertebrate remains from a cave near Montagu, north west Tasmania', *Rec. Queen Victoria Mus.*, Launceston, 60: 20.

Nicolls, K.D. (1960) 'Erosion Surfaces, River Terraces and River Capture in the Launceston Tertiary Basin', *Pap. Proc. Royal Society Tasmania*, 94: 1-12.

Nicolls, K.D. and Dimmock, G.M. (1965) 'Soils', *Atlas of Tasmania*, Lands and Survey Department, Hobart.

Nye, P.B. and Blake, F. (1938) 'The Geology and Mineral Deposits of Tasmania', Tasmanian Mines Department, *Geology Survey Bulletin*, No. 44.

Olive, L.J. (1974) *Sediment Yield of Three small Catchments in South-East Tasmania*, University of Tasmania (unpublished).

Orchiston (1979) 'Pleistocene sea-level changes', *Mod. Quat. Res. S.E. Asia.*

Patersen, S.J. (1967) 'Tertiary Deep Lead Deposits, Moina Area', *Paper and Proceedings of the Royal Society of Tasmania,*, 101: 258-260.

Paterson, S.J. (1966) 'Pleistocene Deposits at Parangana Dam site in the Mersey Valley', *Pap. Proc. Royal Soc. Tas.*, 100: 147-151.

Paterson, S.J. (1965) 'Pleistocene Drift in the Mersey and Forth Valleys – Probability of Two Glacial Stages'. *Pap. Proc. Royal Soc. Tas.*, 99: 115-124.

Paterson, W.S.B. (1981) *The Physics of Glaciers*, 2nd ed., Pergamon.

Patterson, D.J., Ohmoto, H.H. and Solomon, M. (1981) 'Geologic setting and genesis of cassiterite - Sulphide mineralisation at Renison Bell, Western Tasmania', *Economic Geology*, 76: 393-438.

Press, F. and Siever, R. (1978) *Earth*, Freeman.

Quilty, P.G. (1972) 'The biostratigraphy of the Tasmanian marine Tertiary', *Pap. Proc. Royal Soc.Tas.*, 106: 25-44.

Rawlings, G.E. (1967) 'Sub-Basaltic Sediments and Metasediments of the Mersey-Forth Area', *Pap. Proc. Royal Soc. Tas.*, 101: 267-270.

Richards, A.M. and Ollier, C.D. (1976)*Investigation and report on the ecological protection of Exit Cave near Ida Bay in Tasmania for National Parks and Wildlife Service, Tasmania*, Unisearch Ltd., University of NSW. 77pp.

Roberts, G.T. and Andric, M. (1974) 'Investigations into the watertightness of the proposed Gordon-above-Olga hydroelectric storage south-west Tasmania', *Journal. Engng. Geol.*, 7: 121-136.

Sanders, N.K. (1965) 'A Shore Platform Reconnaissance of Tasmania', Abstract, *ANZAAS 38th Congress*.

Sanders, N.K. (1968) *The Development of Tasmanian Shore Platforms*, Ph.D. Thesis, University of Tasmania.

Scanlon, A. (1984) *The Geology of Tasmania*, Education Dept. Tasmania.

Sigleo, W.R. (1978)*A study of late Quaternary environment and man from four sites in southeastern Tasmania*, Ph.D. Thesis, University of Tasmania.

Sims, P.C. (1970) 'Note on Aboriginal Petroglyphs at Devonport, Tasmania', *Pap. Proc. Royal Soc. Tas.*, 104: 117-118.

Skemp, J.R. (1963) 'A History of the NW coast from its Discovery to the Present Day', *Tasmanian Educator*, April, 7-19.

Smith, E. and Williams, E. (1965) *Geological Excursions for the Australian and New Zealand Association for the Advancement of Science. 38th Congress*. Department of Mines, Hobart.

Solomon, M. (1981) 'An introduction to the geology and metallic ore deposits of Tasmania', *Economic Geology*, 76: 194-208.

Spry, A. (1957) 'The Precambrian Rocks of Tasmania, Part II: The Mount Mary Area', *Pap. Proc. Royal Soc. Tas.*, 91.

Spry, A. (1958) 'The Precambrian Rocks of Tasmania, Part III, Mersey-Forth Area', *Pap. Proc. Royal Soc. Tas.*, 92: 117-137.

Spry, A. (1960) 'Pieman Development: Geology of the Mount Donaldson Area', Unpub. Report to H.E.C., Tas.

Spry, A. and Banks, M.R. (1962) 'The Geology of Tasmania', *Journal Geological Society of Australia* 9: 2.

Stevens, G.R. (1980) *New Zealand Adrift*, A.H. and A.W. Reed.

Strakhov, N.M. (1967) *Principles of Lithogenesis*, Oliver and Boyd.

Sugden, D.E. and John, B.S. (1976) *Glaciers and Landscapes*, Arnold.

Sullivan, W. (1974) *Continents in Motion*, McGraw-Hill.

Sutherland, F.L. (1980) 'A Tale of Two Continents', *Australian Natural History* 20, 2.

Tasmania, Mineral Resources and Mining Industry (1981) Dept. of Mines.

Tivendale, B. (1983) *Soil Conservation*, Education Department of Tasmania, Hobart.

Twidale, C.R. (1957) 'A Reconnaissance of the Corinna-Pieman Heads area Geomorphology', *Pap. Proc. Royal Soc. Tas.*, 91: 8-16.

U.S. Committee for GARP (Global Atmospheric Research Program) (1975) *Understanding climatic change*, National Academy of Sciences.

Van de Geer, G. Colhoun, E.A., and Bowden, A. (1979) 'Evidence and problems of interglacial marine deposits in Tasmania', *Geologie en Munbow*, 58, 1, 29-32.

Van de Geer, G. (1981) *Late Quaternary marine and freshwater swamp deposits of northwestern Tasmania.*, Ph.D. Thesis, University of Tasmania.

Veevers, J.J. (ed.) (1984) *Phanerozoic earth history of Australia*, Oxford University Press.

Walker, K.R. (1958) 'The Geology of the St. Helens - Scamander Area, Tasmania', *Pap. Proc. Royal Soc. Tas.*, 91: 23-39.

Walshe, J.L. and Solomon, M. (1981) 'An investigation into the environment of formation of the volcanic - hosted Mt. Lyell copper deposits', *Economic Geology*, 76: 246-284.

Ward, L. Keith (1951) *Underground Water in Australia*, Tait Publishing Co.

Webby, B.D. (1981) 'The Ordovician System in Australia, New Zealand and Antarctica', *International Union of Geological Sciences*, Pub. No. 6.

Weier, T.E. et al (1974) *Botany: an introduction to plant biology*, Wiley International Edition.

Wells, A.T. (1957) 'Geology of the Deloraine - Golden Valley Area', *Rec. Queen Victoria Mus.*, Vol. 8.

Williams, E. (1978) 'Tasman fold belt system in Tasmania', *Tectonophysics*, 48: 159-205.

Index

Acropolis, 77
Adamsfield, 128
Africa, 143
Albert Rapids, 70
alluvial fans, 59
Alpine Periglacial environments, 114-116
Andrew River, 72
Anna-Kananda, 51
Anson's Bay, 93
Antarctica, 10-11, 99, 102-103, 137, 142
aquicludes, 39-40
aquifers, 39, 46-47
Arch Island, 90
Arm Glaciation, 113-114
Arm River, 113
artesian water, 48
Arthur Lineament, 126
Arthur Range, 100
Arve River, 62
Austin's Ferry, 79
Badger Head, 19, 75, 126
barchan, 120
bars, 92
barriers, 92
barrier islands, 94
Bass Basin, 140-142
Bass Strait, 83, 85, 89, 95, 97-98, 103, 117, 140-141
batholiths, 2
Bathurst Harbour, 98
bayhead beaches, 92
baymouth spits, 82, 92-93
beach cusps, 84
Beaconsfield, 75, 126, 128, 133
Bedlam Walls, 77
Bell Bay, 126
Ben Lomond, 74, 100, 114, 116
Berriedale, 94
Bicheno, 138
Blackman Bay, 95
Blackmans Bay, 42, 86, 88-91
Blinking Billy Point, 80
block streams, 116
blowholes, 90-91
Boat Harbour, 89
Boco Valley, 111
Boobyalla, 140
braided channels, 56
Bridgewater, 79, 103, 122
Bridport, 96, 121, 133
Brighton, 29
Bruny Island, 19, 47, 80, 94, 96
Bulgobac Valley, 110
Burnett Lagoon, 92
Burnie, 89, 126, 136
Bushy Park, 79, 142
Butlers Gorge, 77-78
Byron Gap, 105
calderas, 130
Cameron Inlet, 93
Campania, 29
Campbell Town, 29, 74-75
Cape Barren Island, 92
Cape Portland, 47, 121, 140
Cape Raoul, 88
Cataract Gorge, 76
Cathedral Mountain, 62, 65
Central Plateau, 99
Chalice Lake, 106
Chapter Lake, 105
Cheyne Range, 72
Circular Head, 96
Claremont, 79
Cleveland mine, 134
Cloudy Lagoon, 94
Coal River, 56, 93, 122
Coles Bay, 134
Collingwood River, 72
Comstock Valley, 107, 111
Continental drift, 10-11
Cornelian Bay, 13, 79
Corinna, 97, 133
Cowper Point, 97
Cradle Mountain, 105
Cradle Mountain - Lake St. Clair National Park, 68, 99
Cracroft, 49
Crater Lake, 68
creep, 20
Cremorne, 98
Cressy, 48, 74
Crimson Creek Formation, 127, 129
Croesus Cave, 114
Croesus Glaciation, 113-114
cuesta, 88
Currie, 44-45
Cuvier Valley, 71, 105
Cygnet, 140
Darwin, Charles, 42
Dead Horse Point, 95
Dee River, 70
Deloraine, 74
deltas, 60
Denison Group, 132
Denison Range, 104
Denison River, 70
D'Entrecasteaux Channel, 80, 97
D'Entrecasteaux River, 52
Derwent Bridge, 109

Derwent Graben, 95
Derwent River, 59, 60, 62, 69-70, 77-80, 90, 95, 97-98, 103, 122, 142
Derwent Valley, 42
Devonport, 46, 84
Diamond Lake, 104
Diana Basin, 93
Don Heads, 89-90
Dove Gorge, 68
drainage patterns, 60-63
Dromedary, 122
Dublin Plains, 113
Du Cane Range, 77
Dundas Basin, 129-130
dunes, 119-123
  coastal, 122
  longitudinal, 120, 123
  parabolic, 120, 123
  transverse, 120
Eaglehawk Neck, 41, 87-88, 91
Earth, The
  changing climate, 6-8
  composition, 1-3
  life forms, 5
  origin and structure, 1
  rocks and minerals, 1-3
  surface changes, 9
Eddystone Point, 96
Eldon Group, 132
Engineer Range, 72-73
Entrance Cave, 52
Eureka Cone Sheet, 139
Evandale, 68-69, 75-76
Exit Cave, 52
Falmouth, 93
Federation Peak, 100
Fern Tree, 65
Fingal, 18, 76, 138
Fish River, 113
Flinders Island, 29, 92-93, 95, 97, 123, 141, 145
flood plains, 59
Florentine Peak, 51
Florentine River, 62, 78
Florentine Valley, 17, 49, 67
Forth, 126
Forth Glacier, 114
Forth River, 60, 69-70, 98, 113
Forth Valley, 96, 99, 114
Fossil Bluff, 60, 141
Frankford, 74
Frankland Range, 70, 100
Franklin River, 49, 70-73, 145
Frederick Henry Bay, 93-95, 97
Frenchmans Cap, 72, 100
Freycinet Peninsula, 88-89, 94
frost action, 18
Frying Pan Island, 94
Geilston Bay, 42
geological time-scale, 4-6
glacial erosion, 104-107
glacial deposition, 107-110
Gladstone, 47
Glenora, 69
Godfrey's Bay, 89
Gondwana, 10, 135
Gordon Group, 132
Gordon River, 49, 63, 67, 70, 73, 103
Gormanston, 110
Grail Falls, 105
Grassy,133
Great Lake, 70, 142
Great Oyster Bay, 62
Greenland, 99, 102-103
groundwater
  and the rock cycle, 41
  in Tasmania, 44-52
  percolation, 39
  porosity, 39
  quality, 45
  types, 38
Growling Swallet, 146
Gulf of Bothnia, 103
gully erosion, 33
Gunn's Plains, 49
Hadspen, 69, 75-76
Hamilton, 108-109, 110
Hamilton Creek Valley, 105
Hartz Mountains, 100, 105
Hastings Caves, 43
Hawley, 89
Heard Island, 129
Hell's Gates, 97
Hellyer, 131
Hellyer Gorge, 136
Henty Glaciation, 111, 112
Henty Peneplain, 107
Henty River, 65, 100, 143
Herdsman's Cove, 79
Hobart, 31, 42, 94, 142
Horeb Falls, 108
Houn River, 70, 80, 98
Hounslow Heath, 68
Hudson Bay, 103
Hutton, James, 1
Ida Bay, 49, 52
igneous rocks, 2-3
Jacksons Creek, 113
jointing, 18
Jordan River, 79, 122
Junee
  cave, 51
  resurgence, 51
  rising, 146
Karst, 48-52
Kempton, 29
Kimberley, 43
King Island, 29, 85, 93-95, 97, 123, 128, 133, 141
King River, 60,66, 70, 72, 100

King Valley, 107, 110
King William Range, 70
Kutikina Cave, 145
krasnozems, 28-29
La Perouse, 100
lagoons, 92
Lake Ayr, 113
Lake Belcher, 109
Lake Cressy, 74
Lake Dixon, 72
Lake Dobson, 109
Lake Dora Plateau, 106, 110-111
Lake Dove, 68 104, 115
Lake Dulverton, 145
Lake Edgar Fault, 143
Lake Fenton, 116
Lake Glenora, 78-79
Lake Huntley, 104
Lake Launceston, 74-75
Lake Margaret, 108, 110-111
Lake Pedder, 70
Lake Rhona, 104
Lake Richmond, 70
Lake River, 122
Lake Rolleston, 108, 111
Lake Seal, 143
Lake St. Clair, 77-78, 101, 105, 108-109
Lake Tiberias, 122, 145
Lake Wilks, 104
Last Glacial, 97
Launceston, 31, 47, 141
Launceston Basin, 122
Launceston Graben, 95
Laurasia, 10
leaching process, 24
Lemonthyme Power Station, 70, 114
Leven River, 60, 63, 98
Liffey River, 67
Lillico, 21, 84, 142
Linda Creek, 112
Linda Glaciation, 111-112
Linda Valley, 107, 110, 112
Little Fisher River, 113
Llanherne Level, 96-97
loam, 27
Loftus Hills, 107
Logan's Lagoon, 93
Longford, 48, 74-75, 122
longshore drift, 82
Lower White Hills, 33
Lune River, 132, 139
lunette, 122
Maatsuyker Island, 88
McDonald Islands, 129
Mackintosh Valley, 108-109
Macquarie Harbour, 62, 93
Macquarie Plains, 42, 79
Macquarie River, 74-75, 122
Maggs Mountain, 113
Marakoopa, 50
Marble Hill, 52
Margaret Glaciation, 110-111
Maria Island, 13, 47, 83, 94, 135, 147
Marine erosion, 86
  erosional features, 86-90
Marine deposition, 91-94
Marion Bay, 93, 98
Marrawah, 121
Mathinna Beds, 132-134
Mary Ann Bay, 96
Mayberry Basin, 51
Maydena, 51, 126, 146
Meander River, 74
meanders, 55
Melbourne Bay, 128
Melton Mowbray, 121
Mersey River, 50, 60, 62-63, 69-70, 114, 144
Mersey Valley, 99, 105, 109-110, 113-114
  glaciation, 113
metamorphic rocks, 3
Midway Point, 41
Misery Range, 62
Mole Creek, 17, 49-51, 146-147
Monpeelyata Canal, 115-116
Moogara Plateau, 79
Moriarty, 46
Moses Creek, 105, 108, 113
Mt Anne, 49, 51, 64, 100, 115
Mt Cameron, 18, 47
Mt Campbell, 115
Mt Charles, 77
Mt Eldon, 107
Mt Field, 62, 78, 100, 114, 116
Mt Heemskirk, 18
Mt Ida, 77
Mt Kate, 68
Mt La Perouse, 104
Mt Lyell, 106, 131
Mt Nelson, 139
Mt Olympus, 77, 105
Mt Owen, 111
Mt Pillinger, 113
Mt Read, 129
Mt Read Volcanic Belt, 129-131
Mt Rogoona, 105
Mt Roland, 145
Mt Ronald Cross, 49
Mt Rufus, 77
Mt St. Helens, 130
Mt Sorell, 110-111
Mt Wellington, 13, 19, 98, 116, 139
Mt Wright, 67
Murchison Range, 111
Mussel Roe Bay, 93
Mystery Creek, 52
New Guinea, 142
New Norfolk, 79, 103
New River Lagoon, 93

New Zealand, 140
Nichols River, 72
Nile River, 59
Nine Mile Beach, 47, 93
nivation cirque, 115
Nive River, 78
Norfolk Bay, 95, 97
North Bay, 93
North Esk River, 68, 74, 76
Oatlands, 145
Ocean Beach, 95-96
Old Beach, 137
Olga River, 73
Orange River, 73
Ouse, 66, 79, 122
Overflow Creek, 51
Oyster Bay, 93-94
Oyster Bay Graben, 95
Palaeoclimatic reconstruction, 7
Pangaea, 10
Parangana Dam, 70, 114
Parmeener Super-Group, 135-136
peats, 27, 30
pedology, 26
Penguin, 88
petrified wood, 42
phreatic zone, 38
Piccanniny Point, 86
piedmont glaciers, 101
Pieman River, 66, 70, 97, 100, 103
Pieman Valley, 112
Pipe Clay Lagoon, 98
Pittwater Valley, 95
plunge point, 81
Poatina, 70
podzols, 28
Point Hibbs, 86, 89
Port Arthur, 13
Port Davey, 125-126
Port Sorell, 89, 93, 96
Precipitious Bluff, 49
Pyramid Island, 144
Pyramid Rock, 89
Quaternary glaciations, 110
Que River, 131
Queenstown, 107
Queen Valley, 107
Railton, 132
Ralphs Bay, 94-95, 98
rapids, 64
Reidle Bay, 94
Remarkable Cave, 81, 90
Renison Bell mine, 134
Richmond, 29
rill erosion, 33
rillen karren, 51, 146
Ringarooma River, 69
Ringarooma Valley, 47
river
  capacity, 55
  capture, 67-68
  competence,55
  deposition of materials, 59
  discharge, 54-55
  diversion, 68-70
  load, 55
  rejuvenation, 65-66
  systems in Tasmania, 70-80
  transportation of materials, 58
  velocity, 55
Robins Island, 97
Rocky Cape, 96
Rosebery, 104, 131
Rose Rivulet, 68, 76
Rossarden, 133
Rowallan Dam, 109, 144
Rowallan Glaciation, 113-114
Royal George open-cut mine, 20
Rubicon River, 93, 98
rund karren, 51
Rushy Lagoon, 47
Russell Falls, 65
St. Helens, 56, 96
St. Leonards, 75, 76
St. Marys, 133, 138
St. Patricks River, 74
Sandford, 94
Sandy Bay, 79
Sassafrass Creek, 51
Savage River, 21, 126, 128
Scottsdale, 28, 47
sea arches, 90
sea caves, 90
sea cliffs, 87-89
sedimentary rocks, 3
Self's Point, 80
Sensation Gorge, 51
Sentinel Range, 17
Serpentine River, 70
Seven Mile Beach, 47, 93-94
Seymour, 93
Shannon River, 70
Shark Bay, 127
shingle beaches, 84
shore platforms, 89-90
Skeleton Bay, 93
Slopen Island, 97
Smithton, 29, 121
soil
  conservation, 35
  development, 24
  erosion, 31-35
  fertility, 31
  profiles, 26
  texture, 27
  type, 25, 28-30
South Africa, 137
South America, 9, 137

South Arm, 80, 94, 96
South Esk River, 59, 68-69, 70, 74 -76, 122
Southport Lagoon, 93
Sorell, 29
spits, 92-94
Spreyton, 48
springs, 40, 42-43
Standard Hill, 51
Stanley, 89, 91, 94
Storm Bay, 77
Storys Bluff, 114
Strahan, 95-96
Strathgordon, 125
stream bank erosion, 34
Styx River, 78
Success Creek, 127
succession, 26
Surprise Valley, 72, 143
Swan Basin, 96
Swansea, 96
Table Cape, 89
Tamar Fracture System, 134, 136
Tamar River, 62, 70, 74 -76, 98, 132
Tamar Valley, 74
Tasman Arch, 81, 90-92
Tasman Peninsula, 86, 136
Tasman Sea, 140
Thureau Hills, 19
tied islands, 94
Tiers fault, 139
Tiger Range, 62, 67
Tiger Range Group, 132
tombolos, 94
Traveller Range, 77
Tunbridge, 29
Tunnack, 45
tunnel erosion, 34
Turner's Beach, 93
Tyenna Peak, 51
Tyndall Range, 104, 107, 110-111
Ulverstone, 91, 96
vadose zone, 38
Vale of Rasselas, 70
ventifact, 119
Verona, 90
Walls of Jerusalem, 105
water cycle, 37
waterfalls, 64-65
Waterhouse Beach, 123
wave erosion, 85
wave refraction, 83, 85
weathering
  chemical, 14-17
  mechanical, 20
  physical, 18-20
Wesley Vale, 46
West Coast Range, 99, 107-108, 110-112, 114
Western Tiers, 19, 74
West Head, 75
Wherrett's Lookout, 51
Whirlpool Reach, 75-76
Whitemore Creek, 67
Wilmot, 65
Wind
  erosion, 35, 118
  load, 118
  landforms produced by, 119-123
Wineglass Bay, 94
Wurawina Supergroup, 132
Wurragara Creek, 113
Wybalena, 19
Wynyard, 89, 135, 141
yardang, 119
Yolande River, 65, 100
Zygomaturus, 145
Zeehan, 133

DEPARTMENT OF
EDUCATION
AND THE ARTS

BEST COPY AVAILABLE